# Analysis of Mental Workload and Operating Behavior in Secondary Tasks while Driving.

Dissertation

zur Erlangung des akademischen Grades doctor rerum naturalium (Dr. rer. nat.)

Vorgelegt der Fakultät für Human- und Sozialwissenschaften der Technischen Universität Chemnitz

im Dezember 2012

von Frederik Platten, geboren am 10.03.1981 in Köln.

CHEMNITZ UNIVERSITY
OF TECHNOLOGY

## Zusammenfassung

In dieser Dissertation werden Situationen untersucht, in denen Fahrer während der Fahrt Infotainmentsysteme (In- Vehicle Infotainment Systeme, kurz IVIS) bedienen. Hierbei wird der Fokus auf Situationen gelegt, in denen Fahrer erfolgreich Nebenaufgaben bearbeiten. Im Gegensatz zu einer Vielzahl von anderen Studien wird hier ein ressourcenorientierter Ansatz gewählt. Im Mittelpunkt steht demnach weniger der Nachweis von Leistungseinbußen in der Fahraufgabe durch zusätzliche Aufgaben. Es wird im Gegensatz dazu herausgearbeitet, durch welche alltäglichen Verhaltensanpassungen Fahrer in der Lage sind, Aufgaben zusätzlich zur Fahraufgabe erfolgreich zu bearbeiten. Dazu werden diese Verhaltensanpassungen messbar gemacht. Ein Hauptaugenmerk wird dabei auf die Faktoren Fahraufgabe, Nebenaufgabe und die mentale Beanspruchung gelegt. Des Weiteren wird der Einfluss verschiedener Nebenaufgaben auf das Verhalten analysiert. Dabei wird insbesondere die wahrgenommene Unterbrechbarkeit der Nebenaufgaben detailliert untersucht.

Die Arbeit besteht aus 3 Teilen: 1. Hintergrund des Forschungsfeldes, 2.Experimentalteil und 3. zusammenfassende Diskussion. Im ersten Teil der Arbeit wird zunächst eine Einführung in das Forschungsfeld gegeben und anschließend ein Überblick über den aktuellen Forschungsstand in Bezug auf Zweitaufgabenbearbeitung während der Fahrt. Im Experimentalteil werden 3 Studien präsentiert, die im Rahmen dieser Arbeit durchgeführt wurden (jeweils in Form einer Veröffentlichung).

In der ersten Studie war das Ziel grundlegende Verhaltensanpassungen in einer Fahrsimulationsstudie nachzuweisen, die es Fahrern ermöglichen Nebenaufgaben erfolgreich während der Fahrt zu bearbeiten. Dabei wurde deutlich, dass Fahrer ihr Fahrverhalten und ihre Eingabeaktivität in einer Nebenaufgabe der jeweiligen Situation dynamisch anpassen. Die Fahraufgabe wurde dabei priorisiert. Die Verhaltensanpassungen waren sowohl abhängig von der aktuellen, als auch von der antizipierten Situation und zeigten sich demnach abhängig von der Variation eines Hinweisreizes auf eine kritische Verkehrssituation. Als die Fahrer vor einer möglichen Gefahr gewarnt wurden (sie diese also antizipieren konnten), wurde insbesondere die Aktivität in der Nebenaufgabe reduziert.

In der daran anschließenden Studie wurde die Rolle der Beanspruchung im Zusammenhang mit den Eigenschaften der Nebenaufgabe näher untersucht. Probanden wurden mithilfe eines Tons entweder auf eine bevorstehende, unbekannte Fahrsituation oder auf eine bevorstehende Geschwindigkeitsreduktion hingewiesen. Es konnte gezeigt werden, dass Fahrer in Situationen, in denen sie den weiteren Fahrverlauf antizipieren und die Nebenaufgabe ohne wahrgenommenen Leistungsverlust unterbrechen konnten, signifikant weniger bedienten. Im Gegensatz dazu zeigte sich in Nebenaufgaben, deren Unterbrechung

einen direkten Leistungsverlust nach sich zog, dass Fahrer auch in kritischen Situation gleich viel bedienten. Dieses Verhalten wurde durch eine höhere Anstrengung kompensiert (gemessen mit einem physiologischen Beanspruchungsmaß). Der Zusammenhang der drei Faktoren Fahraufgabe, Nebenaufgabe und Beanspruchung wurde hierbei deutlich. Des Weiteren konnte der Einfluss der Eigenschaften der Nebenaufgaben deutlich gemacht werden: Nur wenn die Unterbrechung der Nebenaufgabe keinen direkten Leistungsverlust zur Folge hatte, wurde diese bereits vor dem Auftreten einer kritischen Situation unterbrochen.

Basierend auf den Ergebnissen der ersten beiden Studien wurde für die dritte Studie ein vereinfachtes Setting entwickelt, das weniger auf der Simulation komplexer Fahrsituationen basiert, mithilfe dessen jedoch dennoch die relevanten Effekte messbar sein sollen. Dadurch wird das Setting unabhängiger von einer bestimmten Simulationsumgebung. Dabei wurde den Probanden sowohl ermöglicht relevante Fahrsituationen zu antizipieren als auch ihr Verhalten daran anzupassen. Des Weiteren wurden Nebenaufgaben analysiert, die ähnliche Bedieneingaben erforderten wie gebräuchliche IVIS, und die zum Teil zeitkritische Eingaben erforderten. Wenn Eingaben zeitkritisch gemacht werden mussten, wurde die Nebenaufgabe erwartungsgemäß seltener unterbrochen, auch wenn eine kritische Fahrsituation angekündigt wurde. Dadurch wurde ein weiterer Einflussfaktor auf die wahrgenommene Unterbrechbarkeit von Aufgaben in Fahrsituationen untersucht.

In den vorliegenden Studien konnte gezeigt werden, dass Fahrer den weiteren Verlauf von Fahrsituationen antizipieren und ihre Aktivität in einer Nebenaufgabe dynamisch und in Abhängigkeit zu bestimmten Eigenschaften der Nebenaufgabe anpassen. Für die zukünftige Bewertung von IVIS wurden dabei relevante methodische Rahmenbedingungen herausgearbeitet und ein mögliches Setting vorgestellt.

## Summary

In this thesis, situations were analyzed in which drivers operate infotainment systems (IVIS) while driving. In this, the focus lay on such situations in which drivers operated these secondary tasks successfully. Following that, a resource orientated approach was chosen in contrast to the focus of many other studies. Demonstrating the negative effects of secondary tasks while driving was less central in this thesis. Rather, everyday behavior adaptations were analyzed that enabled drivers to operate secondary tasks successfully while driving. Therefore these adaptations were measured with regards to the following three factors: driving task, secondary task and mental workload. Additionally the influence of several secondary task attributes was analyzed. Thereby especially the perceived interruptibility was researched in detail.

The thesis contains 3 different parts: 1. Introduction to research field, 2. Empiric part and 3. Overall discussion. In the first part an introduction and an overview of the current research concerning secondary task operation while driving is presented. The second part contains 3 studies, each presented in manuscript form.

The goal of the first study was to show basic behavior adaptations in a driving simulator study that enables drivers to operate secondary tasks while driving. Thereby it became obvious that drivers adapted their driving behavior as well as their activity in the secondary task dynamically to the specific situation. The driving task was prioritized thereby. The adaptations were dependent on the current as well as the anticipated development of the situations and correspondingly sensitive to the variation of a cue to a hazardous driving situation. If drivers were warned (and thereby an anticipation was possible), they reduced especially their activity in the secondary task.

In the second study the influence of mental workload and the attributes of a secondary task were analyzed in-depth. Drivers were informed by a noise signal either about an upcoming unknown driving situation or about an upcoming speed reduction situation in this study. It could be shown that if a secondary task can be interrupted without a perceived decline in performance, it is interrupted in demanding driving situations. If an interruption causes a perceived performance loss, the task is interrupted less often, and so the workload is increased (measured with a physiological measurement). Thus, drivers compensate their current demands by behavior adaptations in different factors, depending on the characteristics of a secondary task. The interaction between driving task, secondary task and workload could be proven by this research. Only if a secondary task could be interrupted without a perceived loss of performance drivers interrupted the task before a hazardous situation was reached.

In line with the findings from the studies above a setting was developed for the third study that is less bound to the simulation of complex driving situations and thereby independent from specific driving simulator settings. Nevertheless the anticipation of further driving situations and the option to adapt behavior was given to the drivers by the setting to measure the effects described above. Additionally secondary tasks were analyzed that have a high comparability to common IVIS. Thus, a focus was on the influence of tasks that require time critical inputs. As expected, in tasks with time critical inputs the activity was less often reduced, even if a demanding driving situation was announced. Thereby another influencing factor to the perceived interruptibility of secondary tasks could be analyzed.

In the presented studies it was shown that drivers anticipate the further development of a situation and adapt their activity in the secondary task dynamically due to several characteristics of this task. For the future evaluation of IVIS, methodological requirements were deduced from the presented studies and a possible setting for further research was discussed.

## Danksagung

Da mich während dem Entstehen dieser Arbeit eine Reihe von Menschen unterstützt haben, möchte ich ihnen an dieser Stelle dafür danken.

Zunächst möchte ich mich bei Josef Krems für die Betreuung und die guten Diskussionen im Vorfeld bedanken. Besonderer Dank gilt des Weiteren Maximilian Schwalm und Andreas Keinath für die Ermöglichung und intensive Betreuung dieser Arbeit bei der BMW Group.

Des Weiteren möchte ich mich bei Natasa Milicic und Julia Hülsmann für die großartige Zusammenarbeit bedanken.

Für die gute gemeinsame Zeit bedanke ich mich bei Jürgen Rossband, Stefan Müller, Juliane Schäfer, Vinzent Rolny, Lutz Lorenz, Svenja Paradies, Jörg Hetterich und Susanne Frohriep (in Reihenfolge ihres Auftritts). Auch der Gruppe von Andreas Keinath, dem ZT-3 MMI Team und dem ganzen Fahrsimulationsteam aus der Halle 25 möchte ich hierbei danken, da durch sie viele Herausforderungen gemeistert oder zumindest angenehmer gestaltet wurden.

Für die Begutachtung meiner Arbeit möchte ich mich des Weiteren bei Mark Vollrath bedanken. Auch gilt mein Dank allen Praktikanten, Werkstudenten und den Teilnehmern an meinen Studien.

Zuletzt möchte ich noch meiner Familie und Jana Franke für die großartige Unterstützung in dieser Zeit danken.

## Content

## Introduction

The number of In-Vehicle Information Systems (IVIS) has been growing continuously over the last years, as well as the traffic volume in general. Thereby the challenges are rising for the driver to reach his destination in a safe and fast way on the one hand, but at the same time the options for car manufacturers to support drivers are growing as well. It can be distinguished between systems which support the driver while driving (e.g. cruise control systems) and systems which can be operated while driving, but are not directly linked to the driving task[1]. This thesis focuses on the operation of the latter systems that are being used while driving (for example audio systems).

IVIS and a variety of different other tasks are operated and performed by a large number of drivers while driving (Dingus et al., 2006; Sacher, 2009). In a naturalistic driving study drivers performed a secondary task in 54% of the study's randomly selected time spans (Dingus et al., 2006). Drinking, eating and talking on a mobile phone or to a passenger are just a few examples of common secondary tasks performed while driving. Driving is referred to as the primary task in this thesis, because of its importance compared to all other tasks. A short example is presented in the following to clarify the focused behavior:

> Imagine a person driving with a passenger on a rural road with low volumes of traffic. While the driver is talking to his passenger he starts to search for a specific song in his audio system. While he is doing that, his route guidance system tells him that the rural road will lead him on to the autobahn within the next kilometer. He therefore stops operating his audio system, continues driving and talking to his passenger until he reaches the acceleration lane of the autobahn. While he monitors the traffic, he accelerates and changes lanes onto the autobahn. During this time he does not talk to his passenger. After he has adapted his speed and his distance according to the other traffic, he starts talking to his passenger again and searches for the music track he was originally searching for until he has found it.

In this example a person is driving and simultaneously operating two additional tasks. One visual-motor task (operating an audio system) and at the same time an auditory/cognitive task (listening and talking to the passenger). All of the tasks are expected to increase mental workload (at least slightly) because they use the same working memory resources (Pashler & Johnston, 1998), even if different modalities are involved. Because of these limited workload resources (Kahneman, 1973), the operation of multiple tasks can lead to a

[1] The focus lies on systems that are related to the tactical or strategically level of control, but not on the operational level in Michons three level model (Michon 1985).

decrease in driving performance. This happens when relevant stimuli are not processed appropriately (wrong interpretation of stimuli or a stimulus is forgotten because of a low processing depth) or even not perceived at all (e.g. tunnel vision, Williams, 1985). In all of the above cases, the driver does not process stimuli into available information, resulting in a lack of information. By analyzing accident protocols two types of errors causing most accidents in automotive traffic situations become obvious: lack of information and wrong decisions/goals (Vollrath, Briest & Drewes, 2006). This demonstrates that secondary tasks can have a strong influence on driver distraction and can raise the possibility of accidents by a reduction of available driving task relevant information. Several studies, national and international projects have tried to measure the influence of secondary tasks on driving safety (e.g.: Carsten et al., 2005 (HASTE); Dingus et al., 2006 (100 car study); Östlund et al., 2005 (AIDE)). For example, an increased risk for accidents was detected when applying makeup (approximately 3.1 times higher than in a baseline driving condition) or when inserting/ejecting a CD (2.2 times higher than the baseline; Klauer, Dingus, Neale, Sudweeks & Ramsey, 2006).

Facing these issues, the central starting point to enhance safety from the view of a car manufacturer lies in the configuration and the design of displays and the optimization of operational interaction concepts of the vehicle. Therefore several projects and studies are carried out by car manufacturers in order to provide an optimal solution (e.g. the Advanced Driver Attention Metrics (ADAM) project or focusing the purpose of usage of a specific system while driving (Niedermaier, Durach, Eckstein & Keinath, 2009) or a specific display technology (Milicic, 2010). In addition to the research done by car manufacturers themselves, several general guidelines and self-commitments exist (for the US the “AAM guidelines” (Alliance of Automobile Manufacturers Driver Focus-Telematics Working Group, 2003) and for Europe the “European statement of principles on human-machine interface” (Commission of the European Communities, 2008)) or are at planning stage (NHTSA, 2012). Principles and rules concerning the interaction with displays and controls are defined in the statement of principles on human-machine interface (Commission of the European Communities, 2008). The system should, for example, not cause long sequences of interactions, and it should not require inputs which are time-critical. Specific values in specific dependent variables are established in the AAM self-commitment to define limits how much a secondary task influences the driving behavior.

In most of the current literature concerning driver distraction and the effects of operating a secondary task while driving, the focus lies on the negative influence of such behavior on different variables (for example the reduction in driving performance, changed glance behavior, the shortened perception or the heightened mental workload). What are the reasons for accidents? How much mental workload does a secondary task produce? Most research tries to answer questions like these (de Waard, 1996; Dingus et al., 2006; NHTSA, 2008; Young et al., 2006). As discussed above, these are important, safety critical questions. On the other hand nowadays more vehicles with IVIS are being manufactured and drivers use them while driving, however accidents are not increasing at the same rate (NHTSA, 2008). This is of course influenced by a range of different variables (e.g. a higher distribution of driver assistant systems, better road conditions, higher quality of driver trainings, etc.). Nevertheless despite the high base rate of drivers who are performing secondary tasks while driving, not much is known about how they do that, what influences their behavior and how it is possible to measure this complex and dynamic dual task behavior.

What is the new approach of this thesis?

Most drivers have experienced a situation described in our example above (or at least comparable situations). But what exactly happens in this every day sequence of drivers' behavior? At first it is obvious that the driver has successfully adapted his (operating) behavior to the driving situation. Different factors seem to play a role here. The driver seems to precisely anticipate the further development of the driving situation. According to that, he adapts his secondary task activity and focuses on the driving scenery. In contrast to the high base rate of successful operations while driving, very little is actually known about the complex mechanisms which make this possible.

In this thesis a resource-oriented approach is chosen to analyze the way drivers act successfully in dual task situations. The ability of drivers to judge a situation according to its current and upcoming demands and adapt their behavior to it is evaluated in this thesis. Every shift of attention away from the driving situation to a secondary task enhances undoubtedly the chance of missing relevant information and this can of course then lead to critical driving situations. Nevertheless drivers often choose to do these secondary tasks and drive free of accidents. This capability is analyzed in this thesis.

## Objective

The main objective of this thesis is to gain a better understanding of how drivers successfully manage dual task situations. Therefore the underlying factors and mechanisms that enable the driver to do so and the demonstrated driving behavior in different situations were analyzed in a detailed way.

To analyze such compensative behavior adaptations three simulator studies were conducted. At first a setting was chosen which offered a lot of degrees of freedom for the driver to react in a driving situation. The chosen secondary tasks were as realistic as possible. The relevant factors for a successful behavior adaptation were extracted and combined in a general framework by this approach.

In a second step, the relation between the different factors concerning the secondary task attributes and the effect on mental workload was evaluated more precisely. Mental workload was measured especially in relation to the driving situation in a continuous, high timescale resolution to attend the dynamic character of such adaptations. The behavior adaptations in secondary task situations and the influence of the attributes of a secondary task on the workload and the performance of a driver were explored.

At last a methodological paradigm was proposed that should enable evaluating an IVIS in regards to its impact on behavior adaptations in an effective way, unrelated to an advanced, specific driving simulator environment. Additionally the influence of time critical secondary tasks (which are comparable to common IVIS) was evaluated. Thereby a better understanding of the secondary task attributes which influence the perceived interruptibility of a task was achieved.

# Theoretical and empirical background

To give an overview of the theoretical and empirical background of the research on driving and performing additional tasks, three main topics are presented in the next chapters: 1.) The driving task: What are the influencing factors while driving a car? How can the driving task be explained from a cognitive perspective? 2.) Operating a secondary task while driving: What are important characteristics of secondary tasks concerning driver distraction? What is the reason for their negative effect on driving performance? 3.) Distraction and mental workload: How can distraction and mental workload be defined?

After this overview, different methods for measuring these three factors are presented. Thereby the different advantages and disadvantages of these methods are discussed. In the last paragraphs of the background section a short summary of the current research situation and an outlook on the afterwards presented studies is given.

## 1 Driving task

Several variables influence our driving behavior every day. For example: the driving environment (e.g. road conditions, weather, etc.), the surrounding traffic (e.g. density, specific behavior of other road users, etc.) and the state of the driven vehicle (e.g. speed, distance to front vehicle, etc.). Various studies are focusing on different driving situations, their demands and the resulting behavior of the driver (e.g. Fuller, 2005; see Vollrath & Krems, 2011 for an in-depth discussion). In this thesis the focus lies on driver behavior and the influence of additional tasks. With this focus the driving task itself should be described. Several models aim to do so. One option is to describe the different levels of control a driver has to monitor while driving. One of the most influential models is Michon’s three level of control model (Michon, 1985). The levels are labeled operational, tactical and strategic. At the first operational level, drivers continuously regulate the vehicle itself (speed, distance to car in front and lane keeping, etc.). The tactical level contains complex maneuvers (overtaking other vehicles, drawing aside, etc.). At the third level strategic tasks, such as navigation tasks, are performed. Regulation at the different levels refers to different time periods (operational: milliseconds, tactical: seconds, strategic: minutes). Different authors have postulated comparable, hierarchical models (Hollnagel & Woods, 2005; Tanida & Pöppel, 2006). In most of these models the relevant tasks operated by the drivers were described, but not the underlying cognitive processes. These can be divided into perception of information, the processing of that information and the execution of action (Vollrath & Krems, 2011).

Most information is perceived via the visual channel (Rockwell, 1988). Although it is difficult to assign numbers to these processes, Hills (1980) estimates that even 90% of the relevant information are visually perceived while driving (see the SEEV model of Wickens, Goh, Helleberg, Horrey & Talleur, 2003). This scanning behavior is strongly influenced by mental workload (e.g. tunnel vision; Wiliams 1985; see also chapter “Mental workload and driver distraction”).

The anticipation of future events is a key part of the processing and the analysis process of perceived information in dynamic situations (Endsley, 1995b). One important outcome of it is a precise expectation of upcoming events. The situation awareness theory describes basic mechanism explaining this. Three different stages are postulated in this model: The situation first must be perceived correctly and then comprehended (second) in order to be able to predict (third) the further development of a situation (Endsley, 1995b). Her model does, however, not supply information about the way people choose a specific action from their anticipation.

According to Baumann and Krems (2007), the Construction-Integration Theory of text comprehension by Kintsch (1998) can be applied here. Thereby, perceived information activates knowledge structures within the long-term memory in the first phase, and in an associated constraint-satisfaction process, relevant structures are integrated into the current situation model. A situation model is here defined as the generalized knowledge of a specific situation configuration. This knowledge depends on information from the long term memory, and contains stimulus configurations, rules and the adequate actions in this situation (Baumann & Krems, 2007; Krems & Baumann, 2009). Perceived information must continuously be compared and integrated to the actual model to update the situation model. The appropriate action for a specific situation is activated if this action fits to the actual situation model. The accomplishment of this action is thereby more likely. Following that it can be postulated that an updated situation model helps a driver to choose adequate actions in a specific situation. The execution of actions in a driving task in general can be described as a highly automated process (if the driver is experienced). Well known tasks can be processed highly automated following the model of Norman and Shalice (1986), even if a lot of information must be perceived and processed. According to their model, triggers and reaction patterns are stored in schemas, which can run without conscious control. Information of the environment are continuously perceived and processed by drivers (mainly, but not only through the visual channel as described above).

# 2 Secondary tasks and driver distraction

Nearly every activity performed while driving can be defined as a secondary task. Shaving, applying makeup, talking to a passenger or eating are just a few which are regularly performed while driving (Dingus et al., 2006). In this thesis the focus lies on the interaction of drivers with devices with visual and manual/visual interfaces in light vehicles while driving. Thereby especially those systems which are not directly linked to the operational level of vehicle control (Michon, 1985) are discussed. These systems were often summarized as IVIS. An example for a secondary task according to this definition is the input of a destination into a navigation system and then driving according to the presented route. An advantage of these systems can be indentified compared to analog ways of finding a route. The manual handling of a paper map, finding a specific destination on the map and extracting the relevant direction information at the next intersection from it, seem to be, at least in the opinion of the author, more distracting than using a navigation system.

Nevertheless the main problem concerning the operation of a system while driving is driver distraction and this should be reduced to a minimum. The exact effect size of distraction caused by secondary tasks and its influence on traffic safety is difficult to estimate. In a naturalistic driving study it was found that in 80% of car crashes and in 65% of near crash situations, inattention was involved (Klauer et al., 2006). Even if these values are not only and directly determined by distraction of an IVIS (a lot of other factors can have an influence on the focus of attention) a lot of research is done and still needed (Regan, Lee, Young & Gordon, 2009) to reduce the amount of IVIS induced distraction as much as possible.

The construct of driver distraction caused by secondary tasks can be divided into three subsets: A) mechanical distraction, B) visual distraction and C) cognitive distraction/increased workload (Tijerina, 2001).

A) In regards to the mechanical distraction of secondary tasks (e.g. reaching for an object) it was found that the influence on accidents is not that high compared to visual or cognitive distraction (Stutts & Hunter, 2003). Nevertheless, to have both hands on the steering wheel enables the driver to react in an optimal way therefore changing that position should be avoided.

B) Visual distraction is in opposite to that a central factor for lane keeping and distance regulation. A suboptimal presentation of information leads for example to 20% longer glances away from the driving scenario (Rockwell, 1988). In regards to this, several guidelines and norms exist concerning the minimization and measurement of visual distraction ("30° rule"; ISO 15008 (2009) for display design, the "AAM guidelines" (Alliance of Automobile Manufacturers Driver Focus-Telematics Working Group, 2003), the European statement of principles on human-machine interface (Commission of the European Communities, 2008), etc.). One important "rule of thumb" here is that glances away from the road lasting longer than 2 seconds should clearly be avoided according to the results of different research projects (see Vollrath & Krems, 2011; AAM guidelines, 2003). Interruptibility of secondary tasks is another central demand (Leiser, 1993). To ensure minimized switching costs between the driving task and a secondary task it is important that a task can be interrupted at any stage (see study three for further discussion). Visibility, distinguishability and interpretability of presented information are additional important criteria for displays (Kantowitz & Sorkin, 1983).

C) Driving and operating an IVIS at the same time can be described as a dual task situation, or even as a multitasking situation. This depends on how specific one task is defined and distinguished from another. In the introduction example it can be argued that multiple tasks were operated at the same time. Goal shifting and rule activation due to the actual operated task thereby strain a control executive (Rubinstein, Meyer & Evans, 2001) and can then lead to an enhanced workload. Due to the fact that mental resources are limited, fewer resources can be used for the driving task if a secondary task is performed. Nevertheless drivers do allocate their attention to a secondary task in specific situations. A distinction has to be made between distraction and an intentional shift of attention away from the driving task. In the first case the attention is not intentionally drawn away from the driving scenery (e.g. by a warning signal). In contrast to that, drivers often allocate their attention to a secondary task and prioritize that task in some situations. It could also be shown that tasks relevant for driving (e.g. a navigation task) were more likely to be prioritized than tasks non-relevant to the driving task (Cnossen, Meijman & Rothengatter, 2004).

Additionally, drivers seem to initiate a secondary task less frequently if they expect a difficult driving situation (Lerner & Boyd, 2005; Rauch, Gradenegger & Krüger, 2009). It appears that drivers are scheduling and interrupting secondary tasks according to the driving situation and their mental workload. These effects will be discussed and analyzed in detail in the studies below. Hockey (1997) postulates in his cognitive-energetical framework that in situations with high demands the effort is not automatically heightened (as postulated by Kahneman (1973) for example), but a supervisory controller regulates the responds. One reaction is thereby that performance goals are reduced and the effort is kept on the same level. In a driving context this means that drivers do not always directly increase their effort (and following this also their workload) if the demand in a situation is ascending. It also depends on the appraisal of a situation by the driver if the effort is heightened in this situation or not.

# 3 Mental workload and driver distraction

Mental workload plays, as a third factor, an important role in safe driving. Driving itself is a demanding task. Several different processes need to be monitored and controlled as it is described in the section “Driving task”. These processes require mental resources. As it will be discussed in the following paragraphs, these resources are limited (Kahneman, 1973;

Pashler & Johnston, 1998). In situations where a driver is operating a secondary task, additionally to the driving task, the mental resources are also occupied by these additional tasks. As a result, a driver is expected to have fewer resources remaining for the driving task, when operating a secondary task. This can lead to a decreased driving performance and an increased risk for dangerous situations.

Mental workload as a construct was first mentioned in the aviation area especially in regards to the air traffic control segment (de Waard, 1996). In these jobs, a lot of different processes, conditions and variables must be controlled simultaneously. Failures in those situations can lead to catastrophic consequences. Therefore a lot of research has been conducted and is still ongoing in order to analyze the mechanisms playing a role in performing well in such multiple task situations. Kahneman (1973) postulated in his fundamental theory of attention that resources are needed to accomplish information processing tasks in general. These resources are in his opinion limited. He defines mental workload as that contingent someone spends on the execution of a specific task (Kahneman, 1973). In addition to this theory, Wickens (Wickens, 1984; Wickens et al., 2003) showed the relevance of the modality in which information is perceived. If a task is presented in two different modalities (for example auditory and visual) and not only via one (for example just in an auditory way) the time sharing processes are more efficient and the workload is expected to be lower. Following that, there are different factors playing a role in how many different tasks can be operated and how many resources are used with that. Another important distinction should be made between *taskload* and *workload* (Hilburn & Jorna, 2001). The so called *system factors* are producing the *taskload* (e.g. demands produced by an interaction with a system interface). The construct of mental workload includes specific operator factors like the skills of a person, a used strategy and the person’s experience (workload and mental workload is used synonymous in this thesis). In contrast to that, the *effort* someone puts into a task can be defined as the voluntary investment of the available resources for the operation of a task (Staal, 2004). Workload describes the personal experience as a reaction to demands (taskload). Therefore it can also be defined as the interaction between the actual demands of a situation and the resources, skills and characteristics of a driver (cf. also O’Donnell & Eggemeier, 1986). With this definition of workload in mind it becomes obvious that one person can have a high workload while operating a given task when someone else has a much lower workload operating the same task. However both have to face the same demands. This is important when comparing different systems and situations: no absolute values should be used, but the workload should be compared within one person between different systems or situations.

Concerning a driving task, cognitive distraction does not directly degrade the driving performance on the operational level of vehicle control; rather the driving situation is not perceived and processed deep enough (Recarte & Nunes 2000) [2]. An everyday example for this is a driver having an intense discussion with a passenger and realizing after a while that he cannot exactly remember what happened during last few kilometers within the surrounding driving environment, even if the driver did not cause an accident. By this the relevance of mental workload in regards to traffic safety becomes obvious: Crucial processes like the update of a situation model require mental workload, if this limited resource is occupied by the operation of a secondary task, an outdated model can further be used and perceived stimuli can be misinterpreted leading to wrong decisions. In order to have a holistic picture of driving behavior measuring mental workload is crucial. Nevertheless, to measure workload with a high level of reliability, validity and a high temporal resolution is difficult. Different measurement methods are therefore presented in the following chapter.

# 4 Measurement methods

Several measurement methods exist to measure mental workload and human behavior in a driving situation or in a secondary task. A selection of them is discussed in the following chapters (see also Vollrath & Krems, 2011). A common way to contrast between different measurements is to compare their validity (see also Bortz & Döring, 2002). Furthermore, focusing the Human–Machine-Interface (HMI) of a specific system, the stage in the development process in which the measurement matches best is another way of differentiating (see figure 1 for a schematic overview).

[2] This effect can probably explain some results of non significant differences between baseline and dual task driving situations.

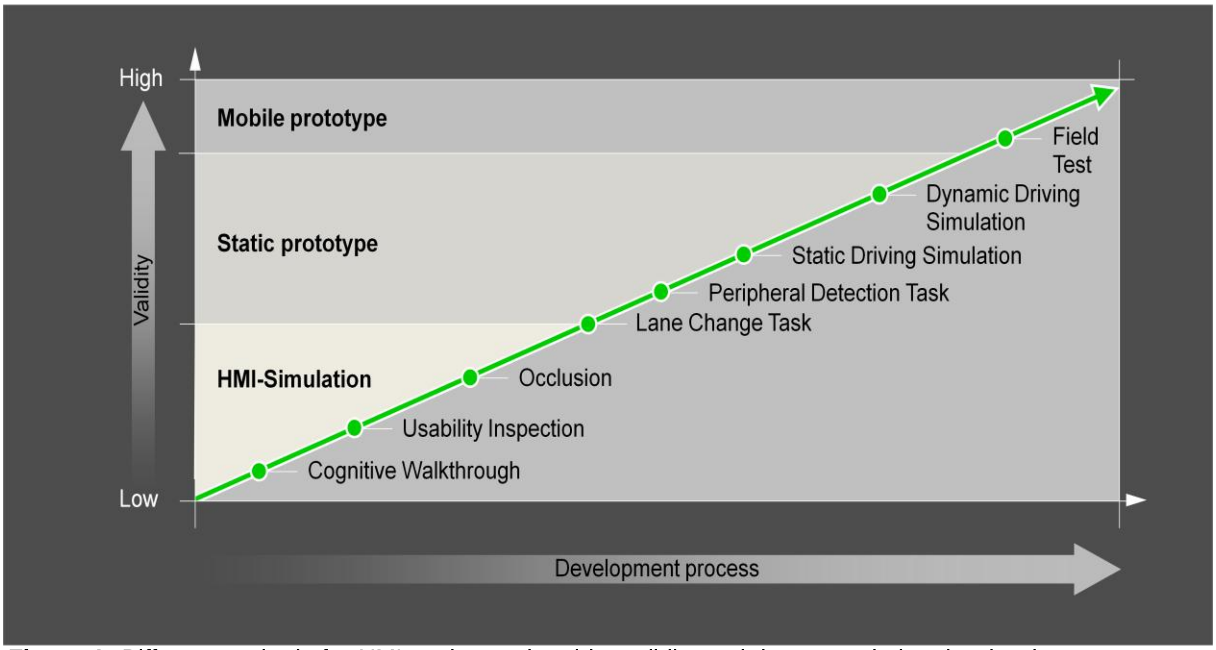



**Figure 1:** Different methods for HMI testing, ordered by validity and the stage during the development process they fit best (Milicic, 2010).

At the bottom left of figure 1 validity is quite low and the development process of a new IVIS is at its beginning. Here methods such as *cognitive walkthrough* or *usability inspection* take place. In these methods an IVIS simulation is rated (mostly) by experts; the systems are not completely operational or even presented in a paper version of screenshots (for an in-depth review of the cognitive walkthrough method see Wharton, Rieman, Lewis & Polson, 1994). Nevertheless, first important assumptions regarding the usability can be made by these methods at an early stage of the development process of an IVIS. The ISO standardized method Occlusion (ISO 16673, 2007) is used to evaluate the readability of screens and interruptibility of tasks (McFarlane, 2002; McFarlane & Latorella, 2002; see chapter Secondary task measurement methods for a detailed discussion of the Occlusion method and the Peripheral Detection task). The Lane Change Task and different driving (simulation) test scenarios will be discussed in the following chapter. In each of the different stages a measurement of mental workload can be feasible, but the most meaningful data (high validity) can be produced especially in situations in which participants are driving (see chapter Mental workload measurement methods).

### 4.1 Driving task measurement methods

Three different methods will be presented here: 1) The Lane Change Task as an example for a basic driving task which requires fundamental driving skills, 2) complex driving simulators with configurable situations and 3) field tests in which the measurements take place in real traffic conditions. The validity is expected to rise among these methods in contradiction to the reliability because of the amount of controllable and non-controllable influencing factors.

### 4.1.1 Lane Change Task

This basic driving simulation was created within the ADAM Project (Mattes & Hallén, 2009). Figure 2 shows a screenshot of the task. Drivers have to change lanes according to the symbols next to the road, as fast and as precise as possible. Thereby different relevant processes of driving need to be processed: First, the perception of a relevant stimulus, then the adequate reaction and maneuver (in this example steer to the right lane), and, finally keeping the lane.

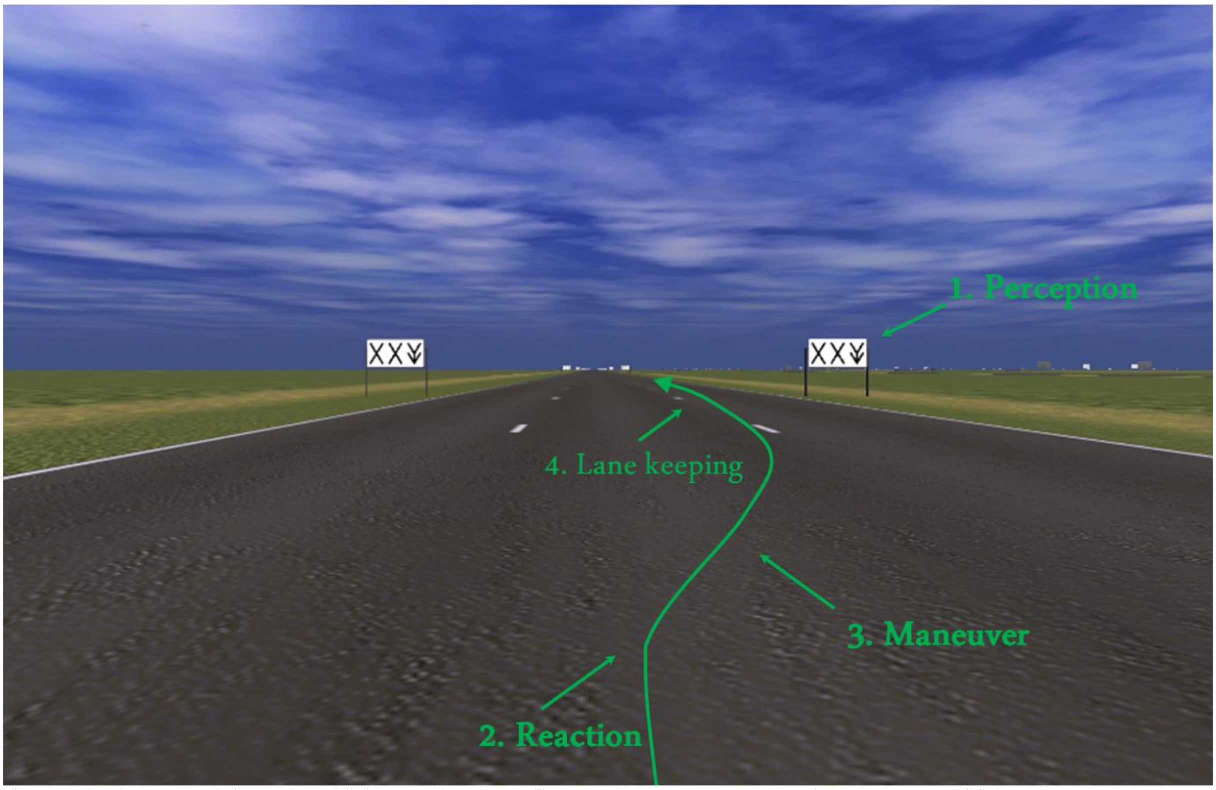



**Figure 2:** Screen of the LCT driving task. According to the ADAM project four relevant driving processes were indicated: Perception, reaction, maneuver and lane keeping.

The driving speed is constantly 60 km/h on a three kilometer course with 18 signs next to the road. The most frequently used dependent variable is the deviation of the measured lane to the ideal lane. Different studies showed that the task is sensible to cognitive distraction (Mattes, 2003; Schwalm, Keinath & Zimmer, 2008). The Lane Change Task can be seen as an easy-to-use tool in order to get a first impression of a secondary task leading to serious problems while driving.

### 4.1.2 Enhanced driving simulator studies

By using modern driving simulator software (e.g. SILAB from Wuerzburg Institute for Traffic Sciences), it is possible to create complex driving situations to evaluate driving behavior in a nearly realistic setting. Thereby different object or time based markers can be used to trigger a reaction of other road users. In figure 3, a screenshot is presented in which a driver has to react for example to different approaching vehicles on a construction site. Various situations are feasible like unexpected obstacles on the road behind a curve, pedestrians crossing the road, or a breaking maneuver of the vehicle ahead. By specifying different if- conditions (like a specific speed of the ego vehicle and a defined distance to a vehicle ahead) it is possible to give participants a realistic degree of freedom (e.g. choosing their speed) on the one hand. On the other hand it is possible to produce situations that are comparable between different drivers (and e.g. their different driving speeds) because a situation is only triggered if specific conditions are fulfilled.

**Figure 3:** Screenshot of a simulated driving situation in a BMW driving simulator.

Especially by using a seating rack (e.g. a half auto body) the situation is perceived more realistically. A setting like this is also useful when testing hazardous situations without any actual danger for the participants or other road users. As operating a secondary task reduces the amount of available mental resources (as discussed above) a driving simulator provides a safe environment for measuring the effects of an IVIS operation. Systems that are not in a maturity phase for an automotive appliance can be tested in such a setting. A lot of different dependent variables can be measured thereby. The complete input to the simulator can be recorded (see table 1 for an overview of often used variables; see Knappe, 2009 for an in-depth analyzes of different variables in a driving simulator).

| | | |
|---|---|---|
| Time of day [sec] | Speed vehicle ahead [km/h] | Pressure on accelerator pedal [event] |
| Steering wheel angle [degree] | Relative speed to vehicle ahead [km/h] | Pressure on brake pedal [event] |
| Odometer ego vehicle [km] | Lane position of ego vehicle [meter] | Deceleration of ego vehicle [m/sec²] |
| Wheel counter left [event] | Distance left wheel to lane [meter] | Current position of ego vehicle [meter] |
| Wheel counter right [event] | Time to collision ego vehicle [sec] | Onset of instruction 1 [event] |
| Time to collision to lead vehicle [sec] | Speed ego vehicle [km/h] | Onset of instruction 2 [event] |
| Distance to vehicle ahead [meter] | Vehicle ahead [event] | Onset of situation 1 [event] |

**Table 1:** Examples of different measurements that can be recorded by a driving simulator.

By using such driving simulator software, the complexity of situations can be enhanced, but of course the variance of the shown behavior is growing at the same time and thereby the required effort for data evaluation grows. Especially in highly dynamic situations it becomes interesting (and demanding) to evaluate driver behavior with a higher resolution over time, unfortunately those in-depth evaluation of dynamic behavior are quite rare yet.

### 4.1.3 Field tests

Field tests in real traffic conditions have of course the highest validity to measure driving behavior. Nevertheless, different disadvantages reduce the applicability of this measurement method[3]. First of all, a lot of factors are not controllable during a field test, for example the behavior of other traffic or the weather conditions. Furthermore the needed efforts of a controlled field test are quite higher than for a simulator study. Additionally, hazardous situations cannot be tested without endangering the participants. Following that, field tests seem to be an adequate method for HMI testing in a late development phase, at a time the system has a high maturity level and for example the acceptance should be evaluated. It can also be a powerful method to analyze for example accidents for traffic psychology in general. Nevertheless, to evaluate potentially hazardous behavior like operating a secondary task in a controlled environment a driving simulator setting seems to be most feasible.

## 4.2 Secondary task measurement methods

To evaluate the interaction behavior of a driver with a secondary task several approaches are possible: 1) if the focus is to evaluate an IVIS itself, the system can be analyzed with or without a driving task or an additional task. 2) If the focus is on dual task behavior while driving in general, a driving task together with a real IVIS is feasible (to enhance the validity). It is also possible to use a driving task with a self-made secondary task (to control precisely the demands for a participant), or even a combination of a driving task, an IVIS and a simulated third task.

Concerning the evaluation of an IVIS (1), a cognitive walkthrough and a usability inspection by experts are good methods to test the usability of an IVIS without any additional tasks (see

[3] See also Vollrath and Krems (2011) for an in-depth discussion of advantages and disadvantages of different measurement methods in field tests, naturalistic driving studies and simulator studies.

discussion above). Additionally the occlusion method, as well as the Peripheral Detection Task (PDT) is an interesting method to evaluate usability. In these methods an IVIS is analyzed in combination with another task (PDT) or a sight modification (occlusion). A driving task is not mandatory here (Vollrath & Krems, 2011).

In the Peripheral Detection Task setting (or more general Detection Response Task) an IVIS is operated and the additional instruction is to prompt signals presented in the environment as fast as they are detected by the participant. Such a signal can be a red light, presented by a diode, or a mechanical vibration. It is expected that the response time and the hit rate is lowered if the demands of a task are higher, especially in areas away from the center of the field of view (Williams, 1985). Nevertheless the PDT is another task in a driving situation that influences the natural interactions of drivers with an IVIS by adding demands to the situation.

Another approach to test IVIS for usage in a dual task situation is the occlusion method. Participants wear specially designed glasses in this task. The lenses of these glasses are alternating nontransparent for 1.5 seconds and transparent for 1.5 seconds during the task (Gelau, Henning & Krems, 2009; ISO 16673, 2007; Keinath, Baumann, Gelau, Bengler & Krems, 2001; Krems, Keinath, Baumann, Gelau, Bengler, 2000; see figure 4 for an example of use). Glances of drivers away from the secondary task to the street are simulated by the nontransparent time spans. The goal is to evaluate the effect of the task interruption to the time that is needed to finish a task. Therefore the Total Open Shutter Time (TSOT) is measured. This measurement is defined as the Total Task Time needed to complete a task (TTT), minus the time during which the glasses are nontransparent. By dividing the TSOT by the time that is needed to finish the task without active glasses (baseline), the index R' results (Gelau & Krems, 2004). This index indicates the interruptibility of a task (Noy, Lemoine, Klachan & Burns, 2004). An R' value above 1 indicates a prolongable influence of the interruption on the time to finish the task. The higher the deviation from 1, the stronger the effect. If R'=1, an interruption has no negative effect to the required time to finish the task. An R' value smaller than 1 indicates that the task can be operated without looking at it, which means a driver can operate a task while looking at the driving environment. Interruptibility is operationalized in this method by measuring the time required for a task with and without interruptions. But, if someone interrupts a task while driving, this can be influenced by additional factors, like joy of use or the expected loss of performance when the task is interrupted. These factors are not in the focus of this method. Furthermore, it is not possible for the participants to influence the shutter intervals, in contradiction to the option of drivers to look longer or shorter at a secondary task while driving. These data can only be evaluated by a setting that allows more degrees of freedom for the driver to control his switches between driving and secondary task.

**Figure 4:** The occlusion glasses used in an experiment at the BMW Lab.

An interesting approach to evaluate the effects of secondary tasks on the driving performance is defined among other things in the Alliance of Automotive Manufacturers guidelines (AAM, 2003). In these guidelines a testing scenario is defined (driving on an autobahn and following a lead vehicle in a specific distance) and several cutoff values for different depended variables are given. For glance duration away from the driving scenario a maximum value is defined and the driving performance (lane departure and distance to front vehicle) is compared to a radio baseline task.

Subjects are able to control their secondary task operating behavior in this setting to a higher degree than in the occlusion setting. Participants can decide in which situations and for how long they look onto an IVIS and at what time they do an input. Following that, such a setting is more interesting if dual task behavior while driving in general is the focus of a study. Nevertheless, for an analysis of secondary tasks even in complex driving situations, these must be realized on the one hand with enhanced driving simulators. On the other hand the data evaluation has to be adequate to the dynamic character of such situations. Only a few studies exist (Lerner & Boyd, 2005; Rauch et al., 2009) that focus on the complex interactions between the driving situation and the input into an IVIS. For an in-depth understanding, it is expected to be important to evaluate input data in relation to the specific driving situation. Thereby, several methodological issues arise which will be discussed in the following articles (standardization of data across different situations and different drivers for example).

### 4.3 Mental workload measurement methods

Several methods exist to measure mental workload in driving situations (for an overview see de Waard (1996) and Schwalm (2009)), as well as in other situations (for an overview see Farmer & Brownson (2003)). Nevertheless, it is a challenging demand for a method to measure mental workload without influencing the participant while performing a task. If for example an additional task is used to monitor the development of mental workload (e.g. the PDT), this task itself can influence behavior and workload of a driver. It is possible that drivers for example prioritize the PDT task over an IVIS task, because they want to avoid missing a stimulus. Thereby the operation of the PDT can produce additional demands itself. This demand can also influence some participants, if they think that their overall workload is too high to drive carefully and therefore lower their driving speed (thereby comparability between drivers who lower their speed and those who do not is negatively affected). Following these thoughts, one requirement of a method which aims to measure workload appropriately is that such interactions are minimized and that the method does not produce additional demands by itself. Another requirement is based on the high dynamics in driving and interaction situations. Demands can rapidly change over time while driving (e.g. demands are high while driving on the acceleration lane of an autobahn, but seconds after that, when driving on the right lane with constant speed, demands can be low again). Therefore, a method is needed that can measure the workload continuously over time with a high temporal resolution.

Workload measurements can be divided into subjective and objective measurements. For a subjective measurement of workload different questionnaires can be used (Barnard et al., 2011). The NASA-Task Load IndeX (NASA-TLX) developed by the NASA contains six subscales: mental demands, physical demands, temporal demands, own performance, effort and frustration (Hart & Staveland, 1988). This questionnaire was developed to measure mental workload in different human-machine interaction settings. The Driving Activity Load Index (DALI; Pauzié & Manzano, 2007) was developed especially for measuring workload in a driving situation. It has the following subscales: mental attention, visual, auditory and tactical demands, stress, time pressure and interference between driving and secondary task. One disadvantage of questionnaires to measure dynamic variables such as workload is that only an overall value can be given for a driving condition[4]. Additionally, in most of the

[4] See O'Donnell and Eggemeier (1986) for an in-depth discussion of questionnaires as workload measurements.

cases the questionnaires are presented after a longer driving phase which can lead to retrospective errors. Nevertheless, subjective data are easy to gain and a good way to compare and crosscheck data of other workload measurements. Another interesting approach to get subjective data is to let participants rate their workload while watching a recorded video of their own performance (e.g. Schießl, Vollrath, Dambier, Altmüller & Kornblum, 2005). Nevertheless, misjudgments between external demands and actual effort (O'Donnell & Eggemeier, 1986) can occur here.

Objective measurements are for example response time, error rates and general performance data in additional tasks. As discussed above, additional demands can arise for drivers thereby, as well as subjective prioritization between the tasks can influence the measurement. Physiological methods can be seen as objective measurements as well. On the one hand these methods need some effort for acquisition and expertise to get valuable data but on the other hand they can deliver data with a high temporal resolution without the risk of retrospective errors and subjective misjudgments occurring (see de Waard, 1996 for further discussion). Especially the Index of Cognitive Activity (ICA; Marshall, 2005, 2007) seems to be an interesting measurement in the automotive context (see second study, chapter Index of Cognitive Activity).

### 4.4 Summary of methodology

Several methods exist to measure driving and operating behavior and mental workload. As all of the methods have advantages and disadvantages the fit to the research question is central for choosing the adequate method. To measure complex interactions and prioritizations between the driving situation and a secondary task input behavior a setting should be chosen that gives drivers a high degree of freedom. The driving task should contain complex situations (e.g. other traffic participants that influence the driving situation dynamically) and drivers should have comparable freedom to choose their actions like they have in real traffic situations (e.g. choose speed in the range of traffic regulations). The secondary task should also be realistic and the drivers should be able to operate it without (sight-) constrains.

A setting like this was realized in the first study of this thesis, and to a smaller degree in the second study. In the third study a more basic setup was used to simplify the setting and increase the reliability of the measurements.

# 5 Explanatory model of a dual task driving situation and procedure for empiric part

Taking into account the findings above, the example in the introduction can be explained as follows: While driving on a rural road the driver estimates that it is possible to operate the IVIS and to talk to a passenger without an overload of his mental resources. When he gets informed that he will reach the autobahn, this information starts a reappraisal process. By processing this information the situation model is updated. - From this point of the example the further behavior and adaption processes of the driver are not certainly predictable from the presented research. Thus the further explanation was tested in the three studies below. - By the update of the situation model, a heightened workload is anticipated, because in the driver's long term memory the process to filter into traffic on an autobahn is stored as demanding. Following that, the best fitting action to the situation model is to reduce the activity in the secondary tasks and maybe additionally to interrupt a discussion with a passenger. After passing the demanding situation the drivers' workload is reduced and he starts his tasks again. Most of the processes are highly automated and performed unconsciously. In this simplified description of a dynamic behavior adaptation the interaction between driving task, secondary task and mental workload is described. This interaction was analyzed empirically in this thesis.

- First question that arose was if and how anticipative behavior adaptations can be empirically shown continuously over time in a dynamic, complex driving situation while using an IVIS (see first study).
- Second, the interactions between the three factors (driving situation, secondary task and workload) were analyzed with focus on the secondary task characteristics. Therefore these and the anticipations of drivers were varied. Workload was measured with a high temporal resolution (second and third study).
- Finally an approach is presented to test IVIS prototypes in a basic setting that enable drivers nevertheless to control their behavior adaptations (see third study).

## Using an Infotainment system while driving – A continuous analysis of behavior adaptations.[5]

Abstract

Despite the fact that drivers are performing a lot of distracting tasks while driving (e.g. usage of infotainment systems) they are usually able to manage difficult situations. Drivers often seem to be able to adapt and effectively regulate their behavior according to the demands of the driving situation. Not much is known about the functional behavior that allows drivers to successfully regulate their intentional demands. The current study aims to investigate these adaptations and provides a methodological approach to do so. 38 participants performed a simulated driving task while using an In-Vehicle Infotainment System (IVIS). Driving data and activity data for the secondary task were recorded and analyzed continuously over time. Participants permanently adapted their driving behavior and particularly reduced their secondary task activity when approaching critical driving situations. To measure these adaptations, a continuous analysis of both driving as well as secondary task behavior is essential.

*Keywords*: Driver distraction; Behavior adaptations; Anticipation

[5] Submitted to *Transportation Research Part F: Traffic Psychology and Behaviour* by Frederik Platten, Natasa Milicic, Maximilian Schwalm, Josef Krems

# 1 Introduction and background

Infotainment systems have become very common in today's vehicles. Currently, almost every new car is equipped with at least an entertainment system and/or a navigation system. Applications during driving are, for example, making a call, manually adapting the driving route to the traffic situation or merely changing the music. Drivers are generally not willing to stop their cars for these reasons. They tend to use these systems in parallel to the driving task instead (Dingus et al., 2006). Therefore, many of these systems have been especially optimized for this purpose (Niedermaier, Durach, Eckstein & Keinath, 2009). The most important goal in designing an infotainment system is to minimize driver distraction when it is used. Diverse commitments exist in which automobile manufacturers bind themselves to fulfill specific requirements (e.g. the European statement of principles on human-machine interface (Commission of the European Communities, 2008) and the guidelines of the Alliance of Automobile Manufacturers (2003)). Most of the studies which explore the impact of the usage of infotainment systems while driving are focusing on error states which occur while they are being used. Various studies have proven the deteriorative influence of a secondary task to different parameters of the driving performance (e.g. Brookhuis, de Vries & de Waard, 1991; Horrey & Wickens, 2002; Manalavan, Samar, Schneider, Kiesler & Siewiorek, 2002; Regan, Lee, Young & Gordon, 2009; Vollrath, Briest & Drewes, 2006). On the one hand, more vehicles with IVIS are produced, drivers are using them while driving (Dingus et al., 2006) and the deteriorative effect of this has been proven by various experiments. On the other hand, accidents are not increasing at the same rate (NHTSA, 2008). This is of course influenced by a lot of different variables (e.g. a higher distribution of driver assistant systems, better road conditions, higher quality of driver trainings, etc.). Nevertheless, drivers usually drive safely in numerous situations although they are simultaneously performing secondary tasks. Furthermore, by observing normal traffic situations it becomes obvious that driving is a highly dynamic process in which the level of environmental demands can change rapidly. In contrast to that – following a broad range of different studies – cognitive resources for dealing with these demands are limited (e.g. Kahneman, 1973). Different factors play a role concerning how many resources can be provided for a task (one of them being the modality of the processed information), but nevertheless the cognitive resources are still limited (e.g. Wickens, 1984). Taking into account that a driving situation can be highly demanding and human cognitive resources are limited, drivers surprisingly often use IVIS while driving and are often still able to perform well in critical situations. In contrast to a failure oriented approach (e.g. Drews, Yazdani, Godfrey, Cooper & Strayer, 2009; Horrey & Wickens, 2002), very few studies examine the processes when drivers are actually able to manage hazardous situations successfully (e.g. Rauch, 2009). Not much is known about the way people usually manage demanding dual task situations without causing an accident, despite the fact that this constitutes a complex behavior adaptation. The central question is how drivers solve the conflict of demanding driving situations and limited mental resources in their everyday driving. In the present paper, associated behavior adaptations are analyzed by means of a simulator study, regarding the driver's ability to anticipate further driving events and different possible behavioral adaptations on an empirical level.

## 1.1 Driving Strategies and Anticipation

To reach the goal of a safe and fast arrival at a chosen destination, drivers have to take into account that their mental resources are limited and that demands can occasionally be very high. Different driving strategies are possible to deal with these demands. Drivers could either try to reduce the demands of a driving situation, or they could try to change the capacity utilization of their mental resources. These strategies manifest on the behavioral level and can only be measured on this level by a detailed look at the dynamic behavioral adaptations of the drivers. For efficient resources management and a reduction of the demands of the driving situation, a correct estimation of the situation and anticipation of its development is essential. The dynamically changing environment and consequently rapidly changing requirements for the driver are important characteristics of a driving situation. To describe these processes, situation awareness is a relevant concept, which has been transferred to automotive application from aviation research. It is employed as a model to describe and predict behavior, especially in dynamic environments (Endsley, 1995). Three different stages of situation awareness are described in Endsley's model: In the first stage the situation must be perceived correctly, on a second level the situation must be comprehended in order to be able to predict the further development of a situation in the third stage. This model does, however, not supply information about the construction of a situation model, of the way anticipation of future events is generated or the way persons choose a specific action. According to Baumann and Krems (2007) the Construction- Integration theory of text comprehension by Kintsch (1998) can be used in this context to provide an expanded theoretical framework: Perceived information activates knowledge structures in long-term memory in the first phase, and in an associated constraint-satisfaction process, relevant structures are integrated into the current situation model (situation model and situation awareness is used synonymously here). To explain the means of specific action choice, the approach of Norman and Shallice (1986) can be used, following Krems and Baumann (2009). In this approach, actions are represented as schemata which activate or inhibit each other. The most active schema will lead to a specific action. In complex situations a control structure – called Supervisory Attentional System – can influence the selection by strengthening the activation of a specific schema. The situation awareness construct can serve to explain an important aspect of safe driving: anticipation of further driving events, based on perceiving and integrating information of the environment. For a safe and failure-free handling of hazardous driving situations the driver has to anticipate the further development of a situation.

## 1.2 Behavior Adaptations to Regulate Driving Demands

If drivers successfully predict a diving situation which is supposed to be demanding, they are able to adapt their driving behavior. A complete model of the way drivers interact with the environment has not yet been comprehensively defined. Following the assumption that drivers try to regulate the demands of the driving situation or the capacity utilization of their mental resources in demanding situations, different behavior adaptations are possible. An obvious and often used adaptation to a demanding situation is to reduce driving speed. This effect is shown in various empirical studies in simulated environments as well as in real driving situations (Jordan & Johnson, 1993; Pohlmann & Tränkle, 1994; Srinivasan & Jovanis, 1997). Another adaptation to a demanding situation which has been empirically proven is the reduction of the number of lane changes in such situations (Beede & Kaas, 2006). Such studies show basic effects of driving behavior adaptations in selected driving conditions.

Besides driving behavior, the operating behavior in a secondary task is essential for understanding the mechanisms of performing a secondary task while driving. Cnosson, Meijman and Rothengatter (2004) postulated that the relevance of a secondary task to the driving task determines the amount of invested effort on that task. Following that, more effort is invested into a task that has a high relevance to the driving task (e.g. typing a navigation destination into a GPS). It could be demonstrated empirically that the cognitive capacity invested in a mathematical task is minor in comparison to that employed in a driving navigation task (Cnosson et al., 2004). Rauch (2009) also measured the input behavior of a secondary task while driving. She identified hesitations during the secondary task operation occurring in difficult situations. In addition, she tried to prove an impact of situation awareness on driving behavior. Her postulation is that the higher the information level is, the better the situation awareness becomes. Drivers seem to adapt their behaviour depending on the given information about the driving environment. In Rauch’s study the participants were asked whether they would start a secondary task in a specific situation or not. However, dynamic adaptations were not analyzed. The continuous progress of apparent compensative behaviour is rarely analysed in detail, despite the dynamic characteristics of a real driving situation. Most studies do not measure the dynamic behavioural changes in complex, hazardous situations in a temporal coherence.

In order to evaluate compensative driving strategies and their measurable consequences, it is important for external validity to observe behavior in a setting in which the driver can operate naturally and behavior adaptations remain possible (see e.g. Engström, Johansson & Östlund, 2005). There is always a risk that the driver's degrees of freedom are limited by the experimental setting (concerning the possibilities for the driver to adapt to a situation), so that natural compensative adaptations do not occur anymore. As an example, if drivers are not allowed to reduce their driving speed in an experimental design and have to start a secondary task which is hard to interrupt, the increase in workload and decrease in driving performance would be an artifact. In this case, the factitious experimental situation produces an effect which would probably not occur if the driver was able to behave naturally and either decelerate or interrupt the secondary task. To avoid artifacts created by the experimental setting and subsequent statistical evaluation, drivers should on the one hand be allowed to drive as freely as possible within the experimental framework in order to give them the maximum degrees of freedom. On the other hand, the development of the driver's behavior adaptations (including the usage of secondary tasks) should be analyzed continuously over time.

There are no distinct forecasts for the temporal development of behaviour adaptations in literature, and it is not clear how robust these adaptations are. The influence of the situation awareness on such behavior adaptations has not been completely defined yet. But some assumptions are possible on the basis of available evidence: According to the hierarchical type of the driving task (Michon, 1985) and the findings of Cnosson et al. (2004), drivers anticipating a hazardous situation decrease their activity in a secondary task, e.g. changing the music track has lower priority compared to a safe arrival at the destination. It follows that drivers actively reduce their workload and focus on the primary driving task in such a situation. Due to the fact that reducing driving speed counteracts the aim of reaching a destination in the shortest possible time, drivers are expected to try to avoid reducing speed, except in situations that they deem it required by an otherwise unsafe situation. The decrease of activity in a secondary task is expected to occur as soon as the driver anticipates a hazardous situation. This assumption is used as hypothesis 1 in this study.

According to the situation awareness theory, different anticipations should lead to different levels of activation of the underlying schemata and produce different behaviour adaptations. If drivers are able to anticipate a hazardous situation, this will allow them to adapt their behavior appropriately to the situation. Hence, behavior is expected to differ between groups with and without a given cue which indicates the development of the further situation (for example a traffic sign). With a given cue, activity is expected to be reduced more and, at the same time, driving speed is expected to be adapted less hasty in critical situations (this serves as hypothesis 2).

The above mentioned adaptations probably occur in diverse driving situations performed by various drivers every day. To verify such behaviour patterns, it is essential to analyze the behaviour as a whole. All dependent variables should be analyzed comprehensively in relation to each other in a temporal coherence.

# 2 Method

## 2.1 Participants and Setting

The experiment took place in a static driving simulator in the BMW usability labs. 38 participants took part in this study, eight of them were female. The average age was 40.7 years (SD: 12.0; range: 22 to 60 years). All of the participants had a valid driver`s license (on average since 22.5 years). The average mileage per year was between 10,000 to 20,000 kilometers. Most of them were BMW Group employees from different departments, and none were paid for their participation.

The participants were seated in the front half of a vehicle which was fully equipped with the original interior equipment of a BMW 5 series. Five projectors produced a 180-degree driving scenery in front of the driver and three 42 inch TFT displays were placed behind of the seat box for rear mirror viewing. Thus, a circumferential visibility of the simulated driving scenery was given. The secondary task was presented on a standard TFT display which was positioned at the upper middle section of the dashboard (following the “30 degree norm”). For the operation of the secondary task two buttons and a turning knob (for list scrolling) on the steering wheel were used. The aim of this study was to analyze driving behavior in a setting as realistic as possible in order to gain as valid and realistic data as possible. Therefore, there were no constraints to driving behavior given by the experimental setting or instructions. The participants started the driving task after they had habituated to the driving simulator and after a training phase for the infotainment system.

## 2.2 Driving Course

The driving course used provided approximately 30 minutes driving time and contained four critical situations. A range of different hazardous situations was realized. Every situation was presented in two versions: with and without a cue to a critical situation. The situations were developed in dependence on a driving course used by Rauch (2009). In situations without a cue was no possibility to predict the hazardous situations. In situations with a cue (see table 1, second column), the cue was presented and became visible approximately five seconds before the actual hazardous situation occurred (since driving speed varied, the period of time differed). With this approach, a substantial difference of the opportunity of a driver to anticipate the development of the situation was produced.

| Situation | With cue | Without cue |
|---|---|---|
| 1. Road work with lane constriction and opposing traffic. | a) Traffic sign „road work ahead“. | b) No sign. |
| 2. Broken down vehicle; located behind a knoll. | a) A warning triangle is placed on the lane before the hill is passed. | b) No cue to the broken down vehicle. |
| 3. Pedestrian crossing the road. | a) Sign “pedestrian crossing” as a cue. | b) Without cue and less visible. |
| 4. Vehicle pulling out onto the lane. | a) The last car in a parking lot is blinking and turns into the lane. | b) The first vehicle (less visible) pulls out. |

**Table 1:** Overview of realized situations.

A distance based trigger was set into the log file at the moment the cue or the hazardous situation itself was presented to the driver and after the situation was passed. In situations in which no cue was presented, a marker was set at the same distance to the point in which the situation was viewable in the corresponding cue situation. Thus, all triggers for all participants were activated at the same distance to the situation independently of driving speed.

## 2.3 Design and Procedure

A between-subject design was chosen for factor *secondary task*: the variation between secondary task group and baseline group (no secondary task). According to this all participants were allowed to drive through the course only once (either with or without secondary tasks) to avoid order effects in case participants remembered the situations. (Baseline n=20, secondary task group n= 18). In the secondary task group, a secondary task had to be performed in every hazardous situation and in other phases of the driving course.

The factor *different type of situation* (the eight different situations) was a within subject factor. Following that, all eight situations were presented to every participant. The order of situations could not be randomized due to technical constrains. Situations with and without a cue were presented alternating. Two versions of the same situation were never presented directly one after another. The experimental situations were presented among common driving situations and embedded in complete scenarios (for example: pass through a village and accordingly reduce speed, stop and let another car pass at a narrow point). Drivers were instructed to drive according to traffic regulations, and safety was to be highest priority. The participants were allowed to take as much time as they needed to complete the tasks; through this, it was attempted to avoid time pressure.

The factor *cue* was also a within subject factor (cue to situation). As it can be seen in table 1, all kind of situations were presented with and without a cue to it.

## 2.4 Secondary Tasks

The participants had to perform the secondary tasks with a prototype infotainment system. Every participant had to finish 16 visual tasks. These were presented through recorded audio instructions, which were started at specified positions on the course. The tasks were frequently used functions (for example making a phone call or changing an audio track). In every task a specific item had to be selected from a list (name, address or music title). The system was operated with a roll element on the steering wheel. The hierarchal structure contained three levels. At the two first levels the participants had to choose one of three menu items, after that an item had to be chosen from a list. The system was designed especially for use in a car, so the task could be interrupted at any point of the interaction. For an in-depth review of the task and the system development see Milicic (2010).


**Figure 1:** Screenshot of secondary task with selected "Navi" item and input element (taken from Milicic, 2010).

## 2.5 Dependent Variables

The driving data and the operational data were recorded with 100 hertz. In order to analyze the driving behavior several variables were analyzed in this study: (1) the maximal deceleration, (2) the time span until the maximal deceleration was measured, (3) the integral of the maximal deceleration, (4) the mean acceleration and (5) the mean driving speed. This list does not claim to be exhaustive, but the above measures were analyzed, because they have often been described as crucial.

The operational behavior in the secondary tasks was analyzed by the averaged activity per second (number of inputs, counted by button pushes). Thereby the driving data and the activity data could be analyzed in relationship to the driving situation.

# 3 Results

In the later paragraphs a discrete analysis (data were summed up over a complete situation) of the data, as well as a continuous analysis (the development of data was analyzed over time) of the driving data and the activity in the secondary task is given. This study focused on successful driving behavior and not failures. All collisions or contacts of the virtual ego vehicle with the environment were defined as driving failures. It was found that the driving failures did not significantly depend on group membership (with and without a secondary task; Kruskal Wallis: p=.10). The 20 situations in which failures occurred (of 304 situations in all) were excluded from further data analysis.

### 3.1 Discrete Analysis of Driving Data

In a first step, the data was summed up over each critical situation per participant (the eight situations described above). A MANOVA was carried out with the factors *cue* (situations with a presented cue versus situations without a cue), *different types of situations* (the four different types of situations described above) and *secondary task* (using the infotainment system (n=18) versus baseline (n=20); no repeated measurement). The dependent variables for the MANOVA of the driving data were: a) maximal deceleration, b) the point in time when the maximal deceleration was measured, c) duration of the maximal deceleration, d) mean acceleration and e) mean driving speed. Missing values were replaced by the respective mean.

Factor *cue*: The factor cue (presented or not) caused a significant effect in behavior data (F Value (5,32)=79.85; p=.001; Wilks lambda=.07). This supports hypothesis 2: Drivers acted differently when they were previously informed about the development of a situation than when they are not. All of the dependent driving data variables were significant: thus, the mean acceleration was lower in situations with a cue than in situations without one (Cohen’s d=1.08), and drivers had a higher driving speed in the condition with a cue than in situations without a cue (Cohen’s d=.29). The maximal deceleration data showed that drivers decelerated stronger in all situations without a cue (Cohen’s d=1.54). In the conditions with a cue, the integral of the deceleration is higher (Cohen’s d=.11) and the time of the maximal point of deceleration was later (Cohen’s d=.46). This means that participants slowed down later in situations with a cue. Concerning the factor *secondary task* the groups differed significantly (Secondary task: F Value(5,32)=4.58; p=.003; Wilks lambda=.58). It could be shown that participants drove significantly faster if they had no secondary task to perform (Cohen’s d=.30). None of the other variables got significant for this factor. As a control factor, the *different types of situations* were also analyzed: The situations were significantly different from each other (F Value(15,22)=145.82; p=.001; Wilks lambda=.01). Here all of the dependent variables were significant.

At this point in the analysis, the data exhibit unexpected results. Why did participants drive faster and braked later if they were warned with a cue? Why did they decelerate more, if they did not get a cue? At first sight these are contradictory results. Thereby the importance and necessity of comprehensive and continuous data analysis becomes obvious. To get a more detailed picture of participants' behavior, continuous data progress is presented in the next chapter, together with an analysis of the activity data in the secondary task.

## 3.2 Continuous Analyses of Driving Data and Activity in Secondary Task

To get a more comprehensive picture of the data, driving speed, deceleration and operation behavior were analyzed together and standardized in chronological sequences. Nevertheless, a methodological problem arose: If someone was driving faster he or she was in another distance to a situation, e.g. one second earlier, than someone who was driving slower. Thus, the criticality of a situation in this second could be completely different for the two drivers. Because of this, it was necessary to define a point (in time or distance) for every participant in order to standardize the different data per participant as a continuum. The second in which the situation was viewable for every participant was therefore chosen to define a reference point in order to standardize the data of every participant according to this point of origin. Additionally to the driving data, the activity data in the secondary task over time was analyzed, too. The activity data contained the percentage of participants operating the infotainment system in this particular second (using the controls). The two figures below show the continuous behavior data of the participants in the road work situation with and without a given cue. For this prototypic situation an in-depth analysis was performed to be able to detail driver behavior. Due to technical problems during data collection only the data of 17 participants in the baseline condition and 18 in the secondary task condition could be analyzed in the dynamic data evaluation.

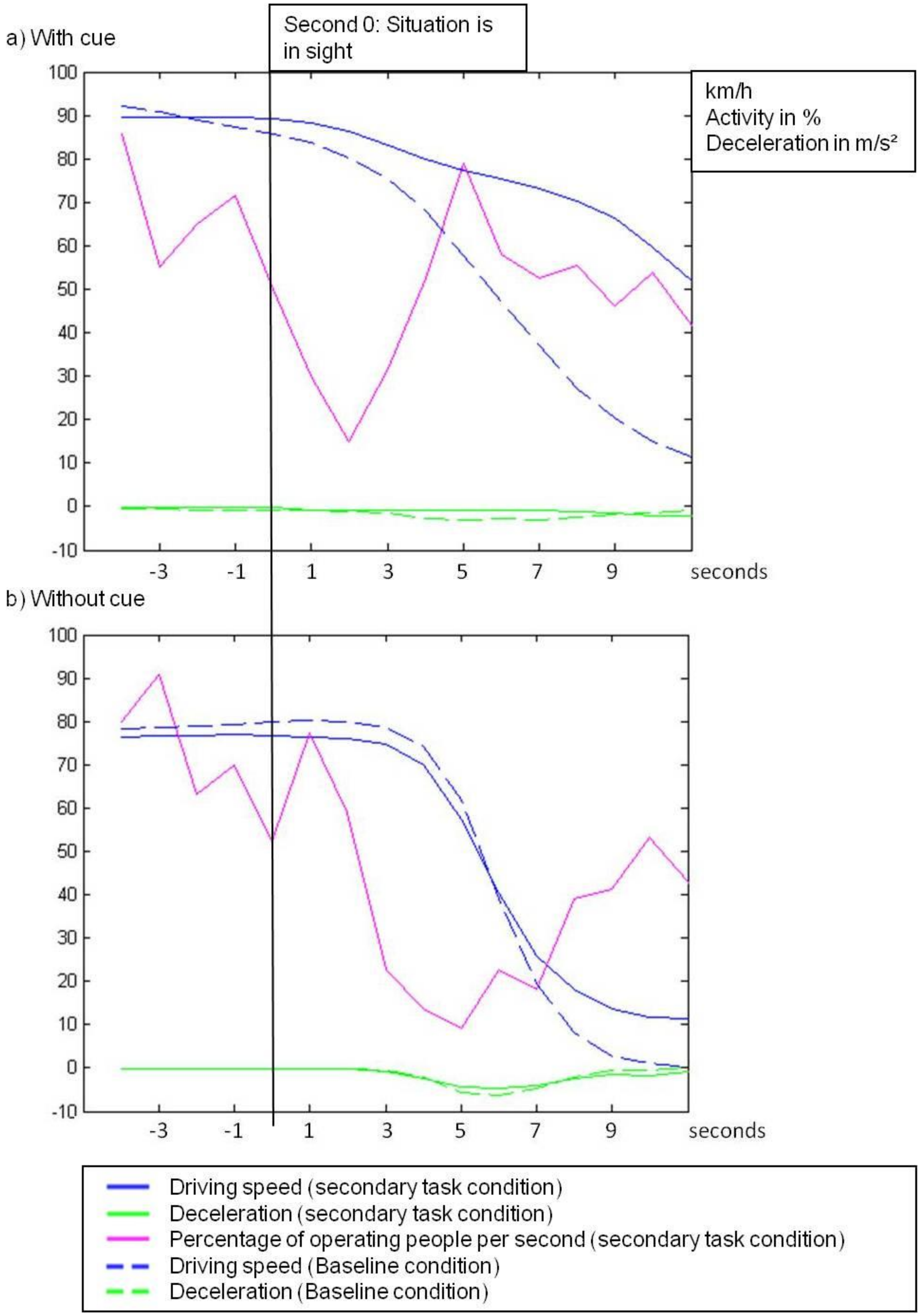



**Figure 2:** Driving speed, deceleration and activity in the secondary task in relation to the driving situation. Condition with cue (a) and without cue (b).

On the x-axis the time in seconds is indicated. One data point represents the average value per second for each given variable over all participants. The y-axis indicates the percentage of people who were using the controls of the infotainment system. Additionally, the y-axis indicates the absolute driving speed in km/h and the deceleration in meter/seconds². The hazardous situation was visible in second zero for all participants, independent of their driving speed. Due to the different driving speeds the graphs were compiled to show the data until 60% of the participants have completed the secondary task (in second 11).

Before the hazardous situation was visible, the speed was slightly higher in the condition with a cue (90km/h compared to 80km/h in situations without a warning). After seeing the situation in the condition without a cue it took the participants longer to drop the speed (approximately from second five) than in the condition with a cue (approximately second three). Moreover, the deceleration was higher in the condition without a cue (approximately 5m/second² to 2m/second²). In the condition when drivers received information about the further development of the situation, participants drove faster but did not decelerate as much as in the condition in which no cue was shown. This behavior has been postulated in hypothesis 2.

In the condition without a cue (figure 1b) the activity in the secondary task reached its minimum later (in second five) than in the condition when no cue was presented (in second two), as expected in hypothesis 1. In both conditions the initial value was about 50% of activity (in second zero). But only if participants got a cue to the situation the activity was reduced in two seconds to the minimum activity of about 10 % (also this percentage is nearly the same in both conditions).

In the condition with a cue the speed at the realized situations differed between baseline and secondary task condition. In the case that a secondary task was performed and a situational development cue was given, participants drove faster than in cases without secondary task performance. This difference did not occur in the condition without a cue. The speed was similar for conditions of performing or not performing secondary tasks.

### 3.2.1 Statistical Analysis of the Continuous Driving Data

To generalize the findings of the presented continuous data of the road work situation, the data of all situations were summed up within relevant time spans. By splitting up the continuous data into relevant segments, a statistical analysis could be conducted. In every different type of situation were some similar central events which could be used to define these time spans: The first critical event in conditions with a cue was the moment when this cue to a situation could be seen by the driver. In conditions without a cue, the same time span to situational view was used. The second, important moment comes up, when the situation itself was seen. The third critical and comparable point in time was the second, in which the maximal deceleration occurred. Finally, passing the situation (e.g. the road construction site) was a comparable moment in all types of situations. According to this, the data were split into three phases (measured in seconds)

1) Moment when the cue was visible to the second when the situation was visible;

2) Moment when the situation was visible to maximal deceleration;

3) Maximal deceleration to passing the situation.

All phases were computed for each participant to compute a repeated MANOVA was computed for 35 participants (Baseline=17; secondary task=18). Missing values were replaced by their respective mean. The dependent variables were mean driving speed and deceleration. The factors were the same as in the discrete data analysis in addition to the specific phase of the situations, as described above. All factors had a significant influence on the variables (factor *secondary task condition*: F Value (2,32) =12.83 p<.01; Wilks lambda=.94; factor *cue*: F Value (2,32)=43.39; p<.01; Wilks lambda=.26; factor *type of situation*: F Value (6,28)=37.20; p<.01; factor *phase of situation*: F Value (4,30)=517.96; p<.01; Wilks lambda=.001). The interaction between the factors *phase* (three phases of all situations) and *cue* (with and without a cue) was significant, too. In the second phase the participants decelerated much more if they did not get a cue (see figure 2). This supports hypothesis 2: Showing a cue produced differences in driving behavior.

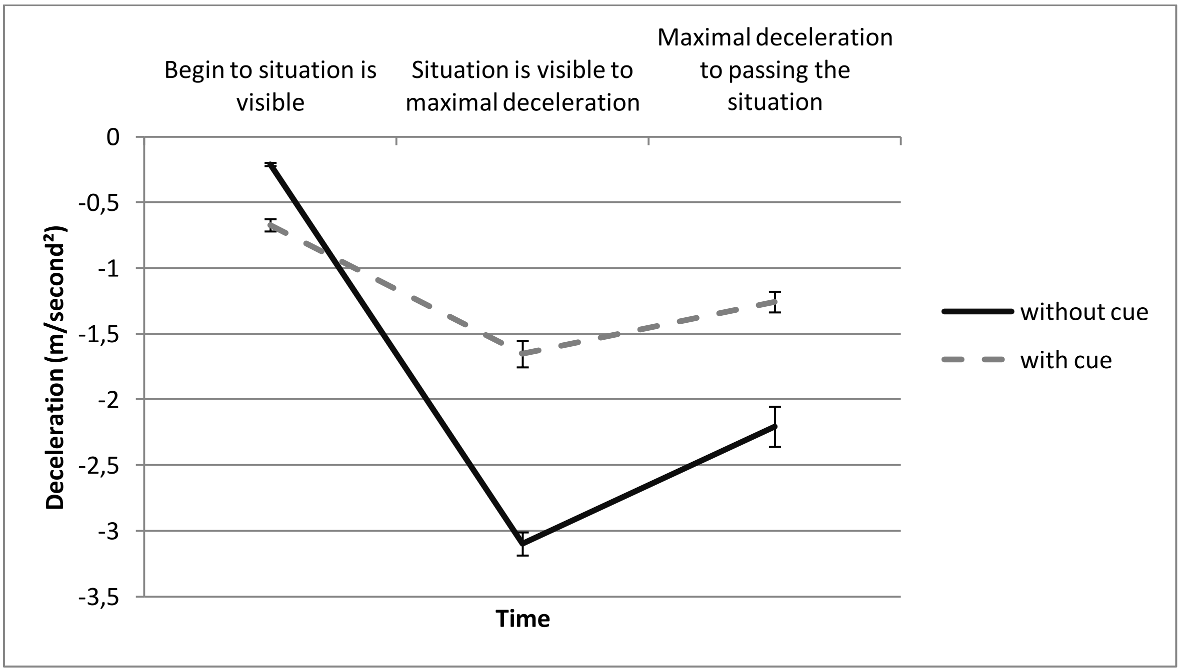



**Figure 3: T**he deceleration in three phases of the situations, with and without a given cue (with their standard deviations). The first time span began in the condition with a cue in the moment the situation was visible. In the condition without a cue the same time span to situational view was used.

### 3.2.2 Statistical Analysis of the Activity Data

For an examination of the activity data in the three phases a repeated ANOVA was computed with the factors *cue* (with versus without a cue), the four *types of situation* and the three *phases of situation*. No significant difference was found between the condition with and without a cue (factor *cue*). This is contradictory to hypothesis 1 (that the activity is reduced if a cue is presented). Nevertheless the activity data in the condition with a cue was lower in phase one and two and only higher in the condition without a cue in condition three (see figure 3).

The factors *type of situation* and *phase of situation* had a significant effect on the performed activity (*situation*: F Value (3,15)=6.23; p<.01; *phase*: F Value (2,16)=30.57; p<.01). Participants interrupted their activity in the secondary task after they had seen the situation (second phase). After the point of maximal deceleration, participants resumed performing the secondary task as can be seen in figure 3.

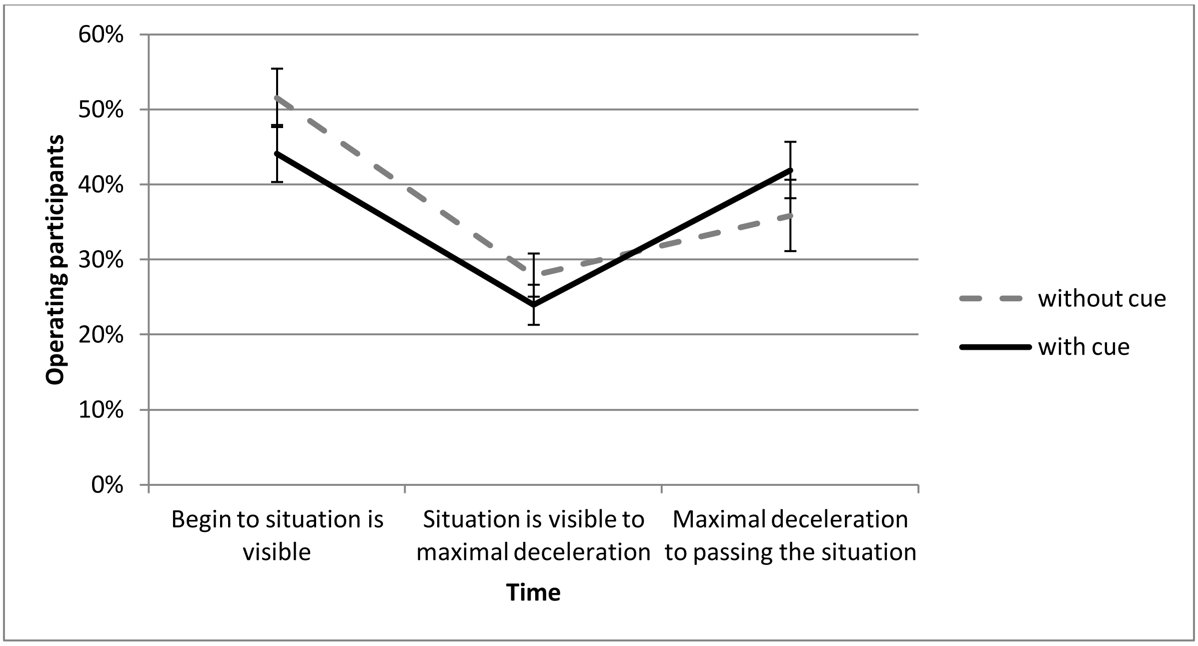



**Figure 4:** The percentage rate of people who operated an infotainment system in three phases of all situations with and without a given cue (with their standard deviations). The first time span began in the condition with a cue in the moment the situation was visible. In the condition without a cue the same time span to situational view was used.

# 4 Discussion

The main goal of this study was to understand how drivers use an infotainment system while driving safely at the same time. Therefore, participants were asked to perform a simulated driving course with hazardous situations, some of which were cued for allowing anticipation.

The first step – comparing measurements that are summed up over the complete situations – yielded counterintuitive results: In conditions in which drivers were cued about an upcoming hazardous situation, they drove faster and braked later. Furthermore drivers decelerated more if they did not get a cue. Performing a continuous data analysis, the results became more reasonable: If drivers received an indication of the further situational development (the cue) they were able to adapt their behaviour and interrupted their secondary task operation earlier than in situations without a cue. Participants also drove faster when they received a cue, because they were able to anticipate the further situational development and did not have to decelerate to such a high extent in the moment the hazardous situation came into sight. The important factor here was the information the drivers received before the situation appears.

It was claimed that drivers interrupt a secondary task to adapt to difficult driving situations dynamically. This assumption was supported by the data of the presented experiment: Drivers interrupted their secondary task depending on the point in time when they attained information about the development of the situation. Therefore drivers adapted their behaviour successfully to requirements of hazardous situations. The same amounts of driving failures were made in the two groups with and without operating an infotainment system while driving. It can be assumed that the reason for this was that drivers were free to intermit the usage of the infotainment system in this study.

The dynamic process of driving behaviour adaptation can be outlined in terms of a comprehension and adaptation process (Baumann & Krems, 2007) as followed: In the first phase the participants were driving and operating a secondary task simultaneously. The activity in the secondary task was high; almost all participants were operating the infotainment system. Such action sequences seem to be well learned and automated. By the perception of a cue to a hazardous situation, specific knowledge structures of the long-term memory were activated and integrated to the situational model. Due to the extraordinary situation the Supervisory Attentional System was activated and inhibited the schemata of operating a secondary task. Operating a secondary task did not seem to fit to the situation model in which a hazardous situation is expected. In line with this, the participants reduced their activity in the secondary task after the dangerous situation was perceived. This was followed by a speed reduction – due to the situation model referring to hazardous situations – until the subjective perceived hazard was passed. Afterwards, the secondary task activity was resumed and driving speed ascended again. This can be interpreted as an indicator that drivers believed that they had the situation completely under their control. The shown behavior adaptations support the central role of a driver's ability to anticipate a driving situation. Similar to the findings of Rauch (2009) drivers were able to adapt their behavior better in situations in which they were allowed to anticipate the development of the situation.

Another remarkable finding is that drivers who were not performing a secondary task (baseline) drove faster over all situations than those who are operating a secondary task while driving (the higher speed in the example presented in figure 1a seems to be an artifact of this situation). A possible explanation for this is that drivers knew that they were distracted while doing a secondary task and were trying to lower the demands of the driving situation by lowering their speed. Drivers, who did not do anything else than the primary driving task, might have felt saver because the situation was not high-demanding. Maybe, they felt able to choose a higher speed because they had the impression to control the situation successfully.

From a methodological point of view the data analysis gave two indications: First it seems that an analysis of continuous data can give important insights how drivers manage hazardous situations dynamically. To reduce data complexity it seems feasible thereby to split the measured data into relevant time spans based on the central events in the situation and to analyze the behavior data according to these segments. Thereby the appropriate segmentation of the time seems to be crucial. A promising way to do so seems to be to split the time spans according the information a driver get in a specific situation. Thus the time spans are comparable between different participants (and their particular driving speeds). Second, it seems to be important to establish a relation between the exact driving situation and the drivers' behaviour. For this reason the coherence of the driving data, the activity in the secondary task and the specific state of the driving situation were analyzed together which proved to be a useful methodological approach of analyzing driving behaviour in general. It is possible to get a much more exact picture of the way people act in complex driving situations with this approach. It is additionally conducive to test the handling of the infotainment system in an environment with a maximum of degrees of freedom for the driver, if natural adaptations are to be analyzed. Therefore the experimental setting was designed to enable a nearly naturalistic behavior.

This study gives an empirical insight into complexity and dynamics of driver behavioral adaptation. Nevertheless, further research is needed to examine the underlying cognitive processes of the exhibited behavior adaptations. Following the approach of Baumann and Krems (2007), the working memory is employed to compare new perceived information with situation models, stored in the long term memory. Selecting the adequate action also demands the central executive (Baumann, Petzoldt, Groenewoud, Hogema & Krems, 2008). In situations in which drivers have to change or question the fit of their current model to a specific situation, the demands to the working memory are expected to increase. Taking into account that drivers seem to compensate a higher demand with different behavior adaptations, it is suggested to measure those interactions and the resulting mental workload. The compensative behavior shown in this study (reducing speed and the activity in the secondary task) is expected to result in a lower mental workload (the effect of mental workload will be therefore analyzed in detail in study 2).

As shown in this study, drivers are often able to handle hazardous situations even if they are using an infotainment system. On the other hand, it is evident that drivers cannot cope with every situation; in that case there would be no driving accidents due to driver distraction. But it is also fundamental not to perceive the driver simply as a reactive object, overstrained by using an infotainment system. In contrast, drivers should be regarded as active managers of their workload capacities, who actively frame a driving situation, influence driving situations actively and adjust their operating behavior to the environment successfully. The reasons why and when those strategies break down must be analyzed more precisely against the background of normally highly functional working strategies.

## Analysis of compensative behavior in demanding driving situations.[6]

Abstract

Drivers usually perform a range of different activities while driving. Following a classical workload approach, additional activities are expected to increase the demand on the driver. Nevertheless, drivers can usually manage even demanding situations successfully. They seem to be able to compensate demands by behavior adaptations, mainly in the following factors: in the driving task itself, in an additional (secondary) task and in their mental workload. It is suggested that by analyzing these three factors in temporal coherence, compensative interactions between them become measurable. Additionally, a reduction of activity in the secondary task is expected to be influenced by the characteristics of this task. To analyze these effects, a driving simulator study with 33 participants was accomplished. It could be shown that if a secondary task can be interrupted without a perceived decline in performance, it is interrupted in demanding driving situations. If an interruption causes a perceived performance loss, efforts are increased, and so the workload is heightened (measured with a high resolution physiological measurement based on pupillometry). Thus, drivers compensate their current demands by behavior adaptations in different factors, depending on the characteristics of a secondary task.

Keywords: Driver distraction; Compensative behavior; Pupillometry; Mental workload

[6] Submitted to *Transportation Research Part F: Traffic Psychology and Behaviour*; by Frederik Platten, Maximilian Schwalm, Julia Hülsmann, Josef Krems

# 1 Introduction and background

A variety of functions is implemented in modern vehicles today. Their number is constantly rising. Modern audio systems as well as route guidance systems with various options and settings can be found in most newly produced vehicles. Nearly every additional activity which is performed while driving (primary task) can be defined as a “secondary task”. For example, discussing with passengers, choosing music tracks from a track list, or setting the route guidance system can be seen as demanding secondary tasks. By observing typical behavior in road traffic, or even one’s own behavior, it becomes clear that most people are performing quite a range of activities while driving (Dingus et al., 2006, Sacher, 2009).

It has often been discussed that performing a secondary task increases mental workload of a driver (see de Waard, 1996 for an overview). If two tasks are handled simultaneously, interferences and conflicts concerning the prioritization of these tasks can occur. The operation of different tasks has to be adjusted according to their relevance, their interruptibility and their time pressure (Kushleyeva, Salvucci & Lee, 2005; Salvucci, 2005). The main problem with an increased workload is that a driver’s mental resources are limited; at least in general (Kahneman, 1973). Wickens (Wickens, 1984; Wickens & Hollands, 2000) has shown that the modality in which a stimulus is perceived plays an important role for the interference of two simultaneously performed tasks: The overall workload while performing two cross-modal tasks is usually lower than operating two tasks which are presented in the same modality (i.e. the workload while performing two visually presented tasks is expected to be higher than the workload in two tasks whereby one is presented in a visual modality and one verbal). Nevertheless, conscious operations seem to use identical working memory resources (Pashler & Johnston, 1998). Such conscious operations are expected to be especially needed in new or complex driving situations. In (driving) situations, which evoke a high workload, it may happen that not all relevant stimuli are perceived (e.g. the effect tunnel vision; Williams, 1985) or that their relevance and meaning for a situation are not properly processed and/or adequately transformed into actions (e.g. Krems & Baumann, 2009). In a naturalistic driving study it could be shown that in nearly 80% of crashes driver distraction played a relevant role (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Nevertheless, these workload theories cannot exhaustively explain why the operation of a secondary task sometimes leads to accidents and sometimes it does not. If the high number of situations in which drivers are performing a secondary task is compared to the number of accidents (NHTSA, 2008), it becomes obvious that accidents occur only in a fraction of those situations. An important question is how drivers manage to perform a secondary task without causing accidents or even lowering their driving performance in the wide majority of cases.

## 1.1 Scope

The focus of this study is the ability of drivers to compensate demands by adapting their behavior or efforts. In this resource-oriented approach, drivers are seen as active coordinators of their demands and resources. The relevant factors of a driving situation are shown and discussed in detail below. Afterwards, different ways to compensate demands between these factors are highlighted. Then, a driving simulator study performed at the BMW research facility with 33 participants is described and discussed.

To analyze a complex driving and operating situation, three central factors which describe the situation from the drivers' perspective must be considered: (1) the driving task itself, (2) the secondary task and (3) mental workload of drivers. Each of the factors influences the drivers' perceived situation and can at the same time also be influenced by the driver. From the authors' point of view, analyzing the interactions of those different factors is crucial for attaining a more holistic understanding of driving and operating behavior. Complex behavior, as driving and performing a secondary task simultaneously, can only be understood completely if the three factors and their interactions are perceived as a dynamic system. Possible interactions of the three factors are shown in figure 1, without claiming to be exhaustive.

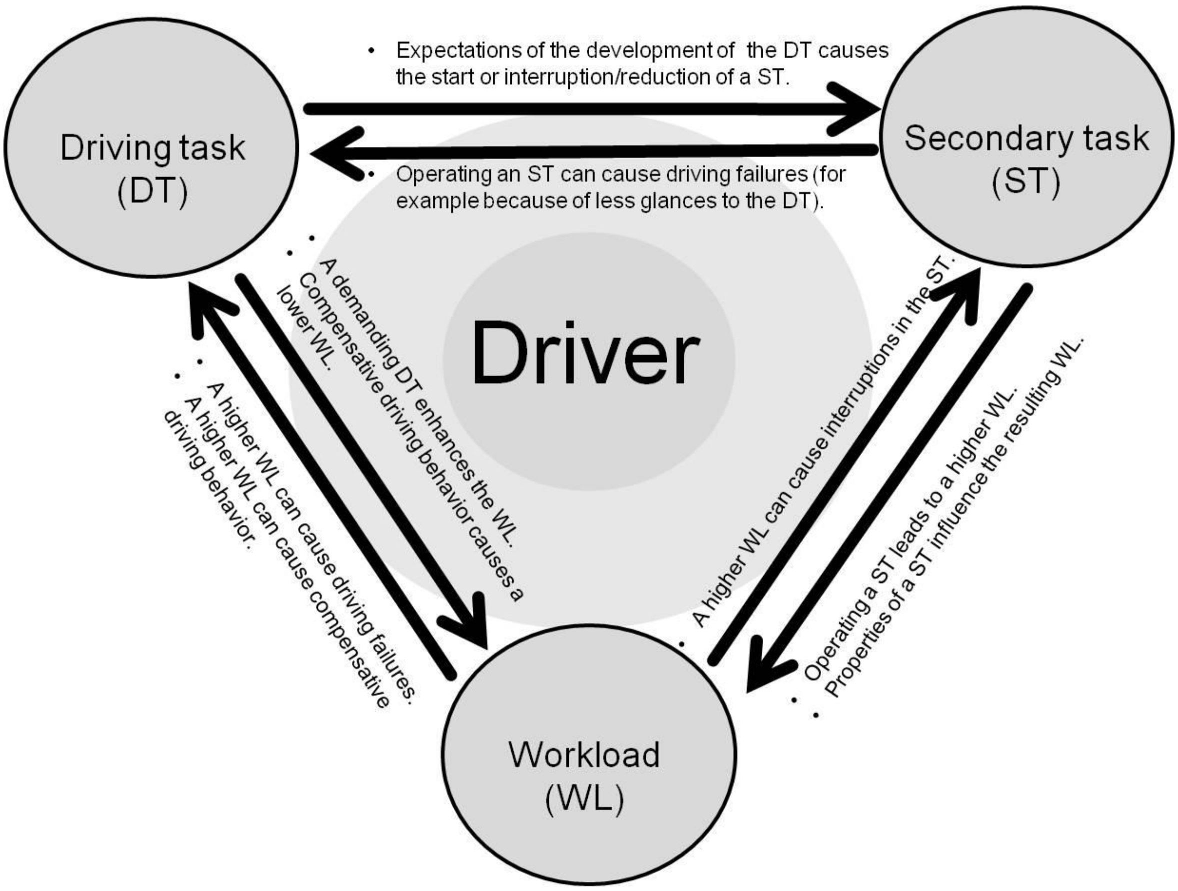



**Figure 1:** Interactive effects between driving task, secondary task and mental workload (without claiming to be exhaustive).

The first factor is the driving task (DT). Different variables play important roles: the driving environment (e.g. road conditions, weather, etc.), the surrounding traffic (e.g. density, specific behavior of other road users, etc.) and the state of the driven vehicle (e.g. speed, distance to front vehicle, etc.). These variables have been elaborated in various studies focusing on different driving situations, their demands and the resulting behavior of drivers (e.g. Fuller, 2005; Sayer, Devonshire & Flannagan, 2005; see Vollrath & Krems, 2011 for an overview).

The second important factor is the secondary task (ST) which a driver is performing while driving. A secondary task is defined thereby as an intended interaction between drivers and their environment (in addition to the driving task itself). Different variables affect usability and the demands of a secondary task (for example the menu structure of the system). Various guidelines and commitments exist, focusing on the design of secondary tasks in vehicles (e.g. the European statement of principles on human-machine interface (Commission of the European Communities, 2008) or the guidelines of the Alliance of Automobile Manufacturers (2003)). Many In-Vehicle Infotainment Systems have been optimized according to these guidelines especially for the purpose of usage while driving (e.g. Niedermaier, Durach, Eckstein & Keinath, 2009). Currently, most research (e.g. Drews, Yazdani, Godfrey, Cooper & Strayer; 2009; Owens, McLaughlin & Sudweeks, 2011; Strayer and Johnston, 2001; Tijerina, Parmer and Goodman, 1998) is focusing on the effect of performing a secondary task in addition to the driving task, as it is shown in figure 1 (arrow from ST to DT). Many studies show the deteriorative effect of performing a secondary task on driving performance (e.g. Alm & Nilsson, 1995; Greenberg et al., 2003; Horrey & Wickens, 2002; Regan, Lee, Young & Gordon, 2009).

The third factor is the current mental workload (WL), which is a special factor in this approach. Here the close relationship between the different factors and the drivers become very clear. Mental workload is defined as the interaction between the current demands of a situation (task load) and the resources, skills and characteristics of a driver (cf. also O'Donnell & Eggemeier, 1986). Following that, this factor is highly influenced by several other factors: The state of the two other factors, as well as personal characteristics, as well as additional influencing factors from the environment. Nevertheless drivers can independently influence this factor for example by changing their effort. Thus, the actual perceived mental workload can rapidly change while driving, depending on the activities of the driver, the surrounding driving scenario and additional factors which are independent from the two other factors (for example thinking about scientific problems while driving or having ambitious aims for managing several tasks simultaneously).

## 1.2 Influences on workload while driving

Driving can be seen as a highly automated process (if the driver is experienced). Well known tasks, such as tracking and regulating a vehicle on the road (Hollnagel & Woods, 2005), can be processed highly automated following the model of Norman and Shalice (1986), even if a wealth of information has to be perceived and processed. This is possible because triggers and reaction patterns are stored in schemata, which can run without conscious control. Environmental information is continuously perceived and processed by drivers. Thereby a precise anticipation of further driving situations is continuously generated. The combination of perception, processing and anticipation of future system states is called *situation awareness* (Endsley, 1995a*)*. In the presented approach, anticipation does not only include further driving situations, but also the expectation of the next steps for secondary task operation and the required workload. This prediction of a future state is possible by an ongoing comparison between the perceived information and a situation model. A situation model is defined as the generalized knowledge of a specific situation configuration in this study. This knowledge depends on memories from the long term memory and contains stimulus configurations, rules, and adequate actions in this situation (Krems & Baumann, 2009). Perceived information must be continuously compared and integrated into the current situation model to update it. The appropriate action for a specific situation is activated if this action fits into the current situation model. The accomplishment of this action thereby becomes more probable. The updated situation model helps the driver to anticipate the probable development of the driving situation (Krems & Baumann, 2009).

If a stimulus which does not fit the current situation model is perceived, a crosscheck with long term memory has to be performed. Through this, it is evaluated whether this stimulus is just an exception within this model or if another model fits better and the current model has to be abandoned. Thus, workload is expected to be increased, because drivers must consciously reappraise the model and potentially change it. If workload is heightened and a secondary task is performed at the same time, drivers have several options to deal with such simultaneous demands.

## 1.3 Different ways to deal with increased demand in a driving situation

Three main adaptations to cope with demands can be deduced from the presented “three-factor approach” (figure 1), regardless if the higher demands result from the driving task or a secondary task. At first, a higher demand can be compensated by changing the current driving behavior. This compensative behavior in the driving task has so far been analyzed in only a few studies (e.g. Carsten et al., 2005; Engström, Johansson & Östlund, 2005; Horberry, Anderson, Regan, Triggs & Brown, 2006). Different kinds of behavior adaptations could be: speed reduction while performing a secondary task is an intuitive adaptation to a demanding situation (for example Caird, Willness, Steel & Scialfa 2008; Jamson & Merat, 2005; Pohlmann & Tränkle, 1994; Törnros & Bolling, 2006). Another kind of compensative behavior is to increase the distance to the vehicle driving in front (e.g. Engström et al., 2005; Ishida & Matsuura, 2001) or to reduce the number of lane changes in demanding situations (Beede & Kass, 2006).

A second way to compensate demands in the secondary task or the driving task is to increase the invested effort (of course this is only possible to a limited extent). The performance in the driving task and in the secondary task can both remain on a high level for a limited amount of time by adding more mental resources.

A third option to compensate demands is to change the operational behavior in the secondary task. The influence of a driving task on the operation of a secondary task has not yet been exhaustively analyzed (arrow from DT to ST in figure 1). One interesting finding is that drivers start secondary tasks less frequently if they expect a difficult driving situation (Lerner & Boyd, 2005; Rauch, Gradenegger & Krüger, 2009). Drivers adapt their secondary task operating behavior to the state of the driving task in order to compensate a difficult situation. A reduction of the activity rate in the secondary task can correspondingly be expected in hazardous, demanding driving situations.

It is the target of this study to analyze in detail the above mentioned third option, the compensative effect of interrupting a secondary task. The factor “secondary task” can be influenced directly by a car manufacturer, particularly by designing systems (secondary tasks) which are easy to interrupt. The perceived interruptibility of a secondary task is expected to be crucial thereby. To translate this assumption into practice, a timeout function in a secondary task is, for example, expected to induce a perceived loss of performance after an interruption. This is expected to happen because the absence of an entry (e.g. in a navigation system) leads to a change in menu position to a previous one (in most cases the main menu). Due to this effect, drivers have to start at the beginning of the menu dialog again and therefore, they will rather try to finish the task before their operation has timed out (for example entering a destination into the route guidance system). If drivers expect that every interruption causes a significant loss in secondary task performance, they will not choose to interrupt their activity in this task as an appropriate behavior and therefore exhibit it less frequently. Instead, they might hazard the consequences in terms of an increased workload. In contrast, a task in which an interruption causes no loss of performance is expected to be interrupted more often rather than accepting a heightened workload.

Following the previous assumptions, several processes can be assumed in a dual task driving scenario: In most cases, drivers are quite capable of performing secondary tasks while driving, because the majority of the processes relevant for the driving process itself are highly automated. To keep this automation level, further driving situations have to be anticipated. Additionally, it can be expected that in a moment, in which an unexpected stimulus is perceived, the situation model has to be re-checked actively. This heightens the driver's workload, and compensative behavior is expected to be shown. If there is no need to re-check the situation model (or just a standard development of the situation is anticipated) the properties of the secondary task are assumed to have no influence on the exhibited behavior. But if there is a need to compensate demands, the interruptibility of the secondary task is expected to influence the exhibited compensative behavior as follows:

a) If the secondary task is interruptable without a perceived loss of performance, the operating activity is expected to be reduced and, at the same time, the mental workload is assumed to be constant or lower because of this interruption.

b) If the interruption of the task results in a perceived loss of performance, the task is not expected to be interrupted, but mental workload is assumed to be heightened (because of a higher effort).

# 2 Method

## 2.1 Participants

33 participants took part in this simulator study, 11 of them were female. The average age was 29 years (standard deviation: 7.92; range 22 to 61). The mean annual mileage was 10000 to 20000 kilometers; all of the participants had a valid driver's license (on average since 12 years). Most of them were BMW Group employees from different departments, and none were paid for their participation.

## 2.2 Experimental conditions and design

In this study, a design with 2 (*type of situation*) x 2 (*type of secondary task*) factors with repeated measurement was used. Two different kinds of driving situations were chosen in order to test the hypothesis that compensative behavior differs according to the anticipated situation. The different situations were expected to induce different anticipations of the further situation. Both kinds of situations were presented repeatedly. In one type of situation, a critical situation was assumed to be anticipated. In the other type of situation, merely a regular driving situation was assumed to be anticipated. For a detailed explanation of the two types of situations see below.

Additionally, two different secondary tasks were chosen to evaluate the hypothesis that the structure of a secondary task influences compensative behavior. The interruption of the secondary task “Surrogate Reference Task“(SuRT) was expected to cause a perceived loss of performance to a lesser extent than the interruption of the “Critical Tracking Task“(CTT). The tasks are described in detail in the next chapter.

## 2.3 Secondary Tasks

Two different secondary tasks were used in this experiment, which critically vary in the consequences of interruption. To interrupt the secondary task CTT caused a direct loss of performance in this task. In contrast, interrupting the secondary task SuRT (Mattes, 2003) did not. In both secondary task conditions, the task was presented on a standard BMW seven inch TFT monitor in the center console (see figure 5).

### 2.3.1 Surrogate Reference Task (SuRT)

Operating the SuRT in this study, participants had to find a target circle in 50 distracter circles. The relationship between size of distracter and target was 100/150 (see figure 2). A grey cursor had to be moved with two buttons on the steering wheel (left and right) onto the target and the position had to be confirmed by pushing a third button, which was also placed on the steering wheel (down). Ten positions were possible for the cursor. All screens were independent from each other and participants were instructed that the number of completed trials was not crucial. Therefore, an interruption was not expected to result in a perceived loss of performance.

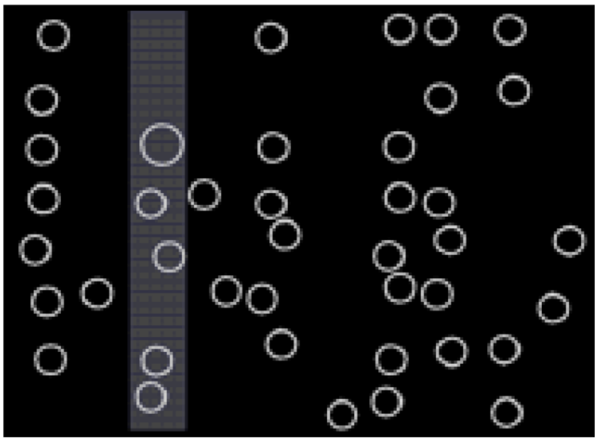


**Figure 2:** Screen of the Surrogate Reference Task.

### 2.3.2 Critical Tracking Task (CTT)

Operating the CTT in the current experiment, a horizontal bar had to be kept in the middle of the display (see figure 3). The bar moved faster in one direction if it moved further away from the middle (with a logarithmical ascending speed, lambda=1). After the bar had moved more than one third of the distance from the middle to the border of the screen, it changed its color from black to red and got bigger. Participants used two knobs on the steering wheel (up and down) to control the bar. The moving direction of the bar (up or down) was random. If this task was interrupted, the performance directly descended due to the permanent movement of the bar. Therefore, it was assumed that an interruption would be perceived as a direct loss in performance.

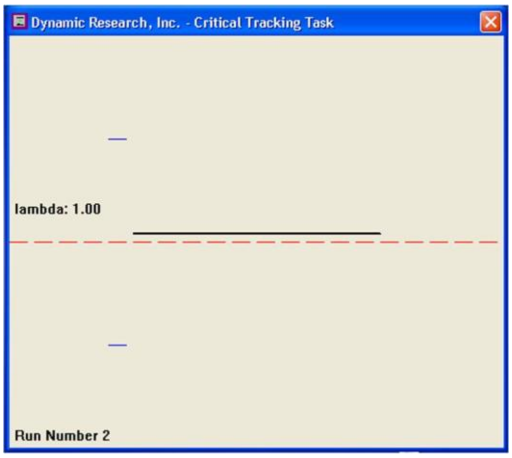



**Figure 3:** Screen of the Critical Tracking Task

## 2.4 Instruments and experimental sequence

The study took place in a static driving simulator of the BMW Group. A half auto body was equipped with the original interior of a BMW 5 series. The driving scenery was presented on six 42 inch TFT displays. Three displays were placed in front of the auto body and three were placed in the back for glances in the rear mirrors.

Prior to the study all participants performed a short training drive to familiarize themselves with the car and the secondary tasks. The participants were instructed to follow a vehicle in front, and to drive conforming to traffic rules. The driving scenery represented a rural environment. All participants drove two courses, taking 30 minutes each. The two courses were selected randomly for every participant from 12 possible courses. All of the courses had a different order of situations. On one of the two driven courses, the secondary task SuRT was operated, on the other the CTT task. Operation order was also randomly assigned to the first and second drive and to the driving courses.

Two different critical driving situations were presented, and they were announced either with a high or a low noise signal. The assignment of the two signals was randomized for the participants. One situation type was called “speed reduction” and the other “unknown situation”. As a cover story, the participants were instructed that the vehicle has two Advanced Driver Assistance Systems. One system could announce speed limit signs ahead, because their positions were stored in the system. Two different driving speed limits, which were lifted after a few kilometers, were used: 50 and 70 km/h. The other system could, due to the cover story, announce a hazardous situation using car to car communication. The participants were told the system was not able to predict the exact kind of situation. A given example for the function of this system was a broken car in front of the ego vehicle which had sent a signal to the ego vehicle. In those situations, a construction site or a broken down van had to be passed.

In this setting, the information about the further development of the driving situation – and thereby the expectations of the driver – were different between the two conditions. The noise level was randomly assigned to one kind of situation per participant and was learned in the training drive. In every course, four speed reduction situations and four different unknown event situations were implemented. The time span between the noise signal and the event was six or nine seconds, respectively (see figure 4). The time span was randomly assigned to the situations. The two different time spans were chosen to avoid an unrealistic precise knowledge about the time lag in which a situation appears.

Participants were instructed to follow a vehicle in front, which reacts adequately to the speed limit, but does not have a car to car communication information system.

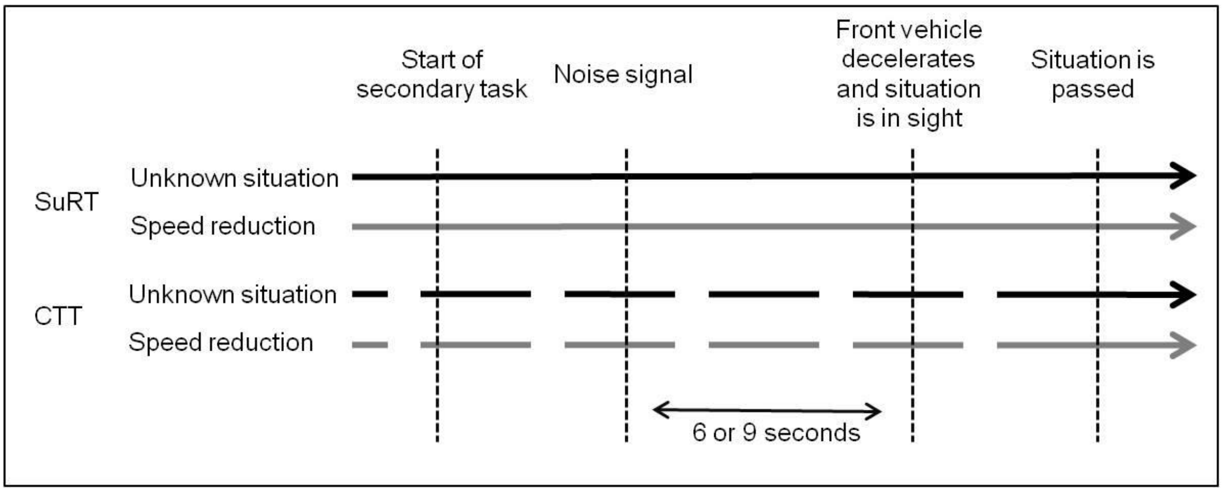



**Figure 4:** The two types of secondary tasks and the two different types of situations.

To reduce the variance of the driving speed between different drivers, a speed control system was implemented into the simulation, which adjusted the speed to 90 km/h. This system was deactivated by using the brake pedal and activated by a steering wheel knob. The system also slowly adapted the distance to the front vehicle to 45 meters, but this function was not communicated to the participants and was operating much too slow to react in urgent driving situations. It was only used to keep the distance to the front vehicle nearly the same to minimize the differences between the situations for different drivers.

In every relevant driving situation (unknown or speed situation), a secondary task was operated. These phases lasted one to three minutes and were announced by an auditory instruction. In some secondary phases no situation occurred to avoid that the secondary task phases were learned as a hint to experimental situations.

Differences in the operating behavior and in mental workload were assumed to be measurable in the time slots of the experiment. The two central time slots for the statistical evaluation of the hypotheses were (1) the interval from beginning of the secondary task until the noise signal occurred (slot “before signal”) and (2) the time slot after the signal until the situation was visible (slot “after signal”). The only difference between these two time slots was the expectation of drivers caused by the signal. In those time slots no special driving activities had to be performed, so the only difference in the operating behavior was expected to be caused by driver expectations.

The front vehicle started to decelerate in the same instant when the situation became visible to the participant. Driving and operating behavior as well as the physiological mental workload were recorded and evaluated in relationship to the driving situation (according to the three different factors in figure 1.) In figure 5, the driving situation is shown from the driver’s perspective.

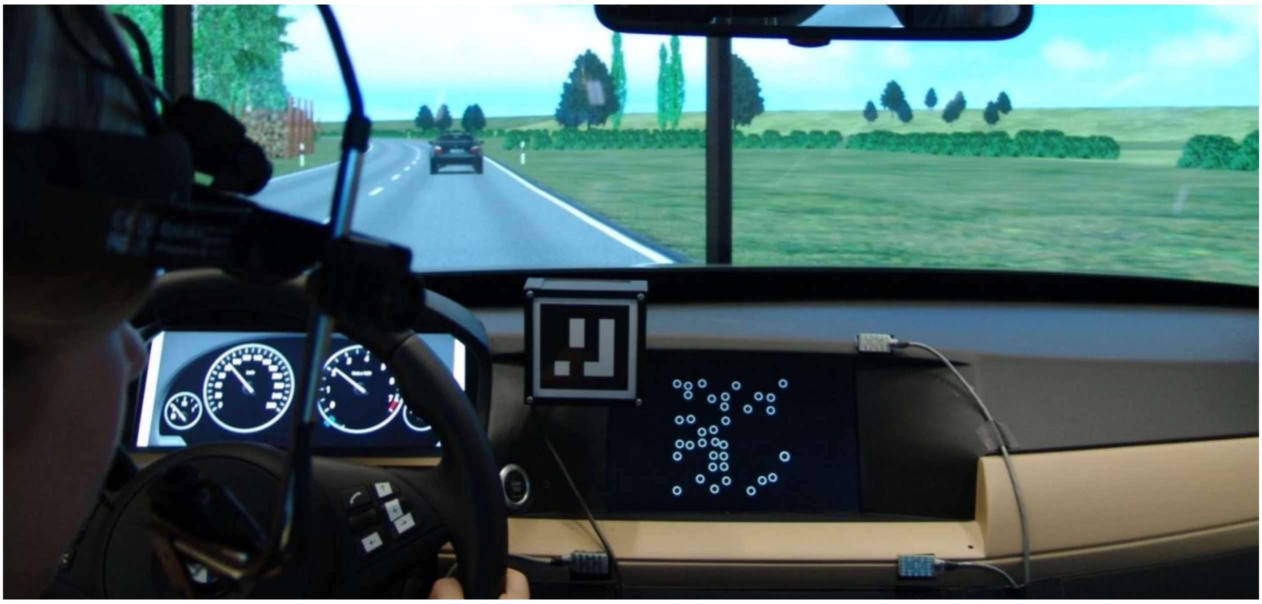


**Figure 5:** Driving scenery with front vehicle and the SuRT task on the central information display

## 2.5 Index of Cognitive Activity (ICA)

Several possibilities exist for the purpose of measuring mental workload (de Waard, 1996). Different methodological approaches are used for this, behavioral data as well as subjective self reports. Using behavioral data – for example a secondary task – has the disadvantage that the entire driving and operating behavior is affected by it. All secondary tasks while driving provoke an additional demand for the driver and cause further compensative behavior.

Another approach is to attain self reports by participants. Different subjective scales are used for this (for example NASA-TLX, Hart & Staveland, 1988). In this case, one issue is the temporal distance from the measurement to the relevant situation (measuring mental workload after the experimental phase). Retrospective errors can occur due to this, and the development of the perceived mental workload is hard to articulate and measure in an accurate way after a time delay. The experimental situation can also be paused for filling in a questionnaire to reduce the time between the situation and the measurement. But the experimental situation is disturbed by this interruption and this can also unintentionally influence the measurement. Additionally, the low temporal resolution can be a problem, because temporal changes cannot be measured precisely (especially short parts of a situation).

Further options for measuring mental workload are physiological measurements. In this case, it is possible to measure mental workload “online” without interrupting the participant. A broad range of different measures have been tested for this purpose (de Waard, 1996). Most of the physiological variables suffer from a high variance between and within participants. A promising approach here is a method called pupillometry, which measures the pupil size. The human pupil reacts to mental demands by changes in size (Hess & Polt, 1964). In this case, the issue is to eliminate other factors affecting changes of pupil size (luminance, for example). For the compilation of the Index of Cognitive Activity (ICA) the size of the pupil is recorded by a 250 Hertz Eyetracker (EyeLink 2). The raw data are transformed with a Daubechies wavelet transformation (Daubechies, 1988). Thereby, only short and fast changes of the pupil are extracted. These bursts of dilation are counted per second, and are a correlate of mental workload (Marshall, 2005, 2007). The range of the index is limited to 0 to 1. It has been shown that it is not affected by other factors than mental workload (Marshall, 2007). The ICA is therefore a physiological measurement which seems to be a good indicator of mental workload also in highly demanding and variable environments. Here, the temporal resolution is much higher than in other measurements. The ICA has been used and approved in an automotive context with basic driving tasks (Schwalm, Keinath & Zimmer, 2008; Schwalm, 2009) and was chosen as a method for the present study.

## 3 Results

The operating activity in the secondary task, mental workload and driving behavior were evaluated. Mental workload was measured with the physiological measurement ICA. By writing local based markers into the recorded data of the simulation and the ICA, the data of all three factors were enabled for synchronization. The data of the time span before and after the noise signal were marked. Situations were excluded from the analyses if the distance of the ego vehicle to the front vehicle was bigger or smaller than 45 +/- 25 meters (6% of the situations). In those cases, drivers had relatively more (or less time) to adapt their behavior than the other drivers and the comparability between the situations was compromised.

## 3.1 Activity in the Secondary task

Every participant's pressing of keys was recorded and synchronized with driving and workload data. The relevant time span here was the time between the noise signal, which announced the upcoming situation and the moment the situation got into sight. To compare the different time slots (6 and 9 seconds, see figure 2), activity data were standardized per second and per participant for each situation, depending on this time span. Additionally, the data were z-standardized within the participants over all situations and conditions. Due to serious technical constraints only the data of 16 participants could be analyzed according to the activity in the secondary task. This data loss was caused by unsystematic failure of measurement equipment and did not correlate with any experimental conditions but was randomly distributed.

### 3.1.1 The effect of different types of secondary tasks, different situations and the number of passed situations.

The activity of participants in the time span after the signal until the situation appeared in sight was analyzed first. A repeated ANOVA with the factors *situation* (unknown situation versus speed reduction) and *secondary task* (SuRT versus CTT) was computed. Over all passed situations, no significant effect could be shown. To analyze if the reason was the number of passed situations, the situations were analyzed according the sequence a participant had driven through. A repeated ANOVA for the SuRT condition with the factors *situation* (unknown situation and speed reduction) and *number of passed situations* (the four unknown situations and the four speed reduction situations) was computed. The main effect *number of passed situations* was significant ($F(3,60)=4.02$; $p<.01$), see table 1 for means and standard deviation. The more situations were passed, the more activity was shown in the SuRT secondary task in both types of situation. The factor *situation* was not significant. A second ANOVA with the same factors was conducted for the activity data of the CTT secondary task. Here no significant effects occurred.

| Type of Situation | Number of passed situation | Mean | Standard deviation |
|---|---:|---:|---:|
| Speed reduction | 1 | -0,18 | 1,19 |
| Speed reduction | 2 | -0,13 | 1,15 |
| Speed reduction | 3 | 0,05 | 0,96 |
| Speed reduction | 4 | 0,1 | 1,18 |
| Unknown situation | 1 | -0,99 | 0,75 |
| Unknown situation | 2 | 0,19 | 1,21 |
| Unknown situation | 3 | -0,01 | 1,08 |
| Unknown situation | 4 | -0,06 | 1,01 |

**Table 1:** Activity in the SuRT task, means and standard deviations (z-standardized values).

Because the number of passed situations influenced the behavior of the drivers, only the first situation of each condition was analyzed in the further analyses. Participants knew after the first passed situation approximately what they had to expect from this situation, thus a learning effect was found. Hence, the participants showed the most authentic behavior concerning an unknown situation in the first situation (this authentic behavior was the focus of this study). The anticipation of an unknown situation and a speed reduction situation thereby became more similar to each other and the observed difference between the two situations became smaller. Especially the activity in the SuRT task was reduced, most probably because the situation was not perceived as "unknown" anymore once the driver had driven through a few of them.

### 3.1.2 The operating activity before and after the noise signal

The data of the time slot before and after the signal were both analyzed (see figure 2). All data were z-standardized within one subject. A repeated ANOVA with the factors *situation* (unknown situation versus speed reduction situation) and *time slot* (before versus after the noise signal) was computed for the SuRT and the CTT secondary task, respectively, as shown in figure 6. The important comparison here is the difference before and after the signal and the difference between the situations. By comparing those data, the measurement paradigm becomes independent from specific tasks and their characteristics.

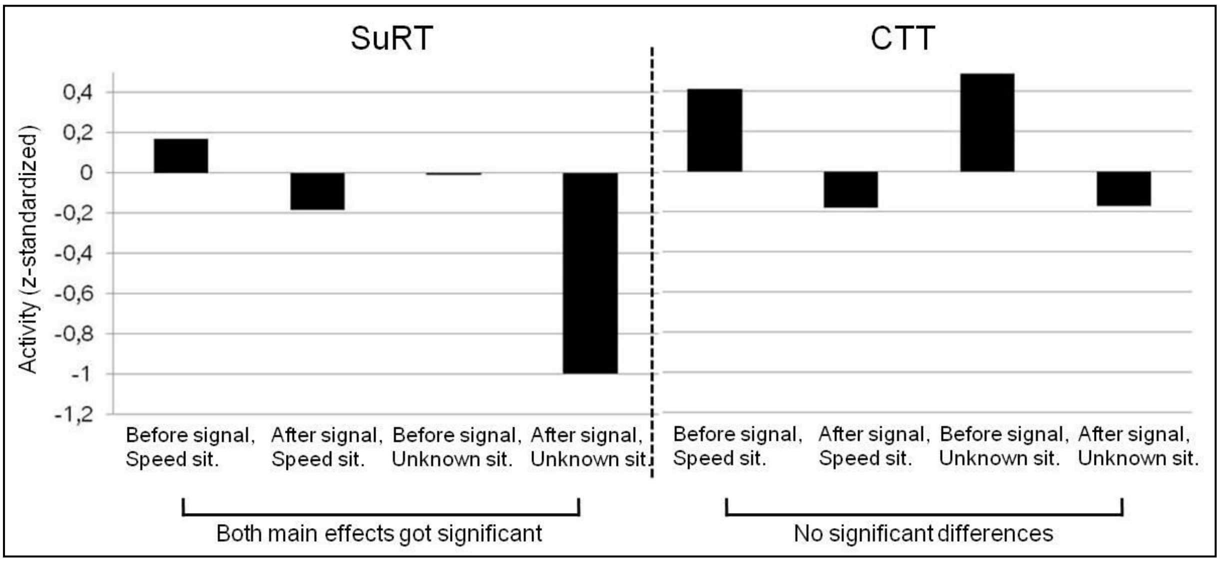



**Figure 6:** The activity in the secondary tasks before and after the noise signal in the two different kinds of situations. See text for specific values.

In the analyses of the SuRT task, the main factor *situation* attained significance ($F(1,25)=5.88$, $p<.02$; Cohen's $d=.62$). In the unknown situation, fewer participants operated the SuRT secondary task than in the speed reduction situations. The main effect *time slot* also became significant in the SuRT task ($F(1,25)=17.87$, $p<.01$; Cohen's $d=.35$). After the noise signal less activity was shown than before the signal. In the analyses of the CTT data, no differences between the conditions were significant. To sum up: drivers seemed to reduce their secondary task activity (and thereby lower their demands) the most in the unknown situation in the SuRT condition, thus the condition they deemed interruptible.

## 3.2 Mental workload

The ICA data were z-standardized from the beginning of the secondary task until the situation was in sight. Outliers (values bigger than two times standard deviation per person) were excluded (according to Schwalm et al., 2008). The data of 33 participants were analyzed.

### 3.2.1 The effect of different types of secondary tasks, different situations and the number of passed situations.

An ANOVA with the factors *situation* (unknown situation versus speed reduction) and *secondary task* (SuRT versus CTT) was computed for the time slot after the signal until the situation came in sight. No significant effects could be shown. To analyze if the reason was the number of passed situations, the situations were analyzed according to the sequence a participant had driven through. The factors *situation* (unknown situation and speed reduction) and *number of passed* situations (the four unknown situations and the four speed reduction situations) were analyzed. No significant effect of the number of passed situations was shown.

According to the analyses of the activity data, further evaluations were computed only for the first speed reduction situation and the first unknown situation a driver drove through, for both secondary task conditions (SuRT and CTT). In a repeated ANOVA with the factors *situation* and *secondary task* no main effect was found, but the interaction between both factors was significant ($F\ (1,32)=4.55$, $p<.04$). In the SuRT condition, mental workload was lower in the unknown situation than in the speed situation. In the CTT condition, mental workload was higher in the unknown situation than in the unknown situation in the SuRT condition.

### 3.2.2 The mental workload before and after the noise signal

An ANOVA was computed to compare the mental workload data in the two time slots before and after the signal. In a repeated ANOVA with the factors *situation* (unknown situation and speed reduction) and *time slot* (before and after noise signal) in the SuRT condition the main effect time became significant ($F\ (1,32)=6.25$, $p<.01$; Cohen’s $d=.35$). A lower mental workload was found in the time slot after the noise signal compared to the time slot before the signal occurred. Additionally, a lower mental workload could be found in the unknown situations (factor *situation*: $F\ (1,32)=4.84$, $p=.03$, Cohen’s $d=.45$). In a repeated ANOVA concerning the mental workload data of the CTT secondary task, none of the comparisons were significant, neither between the time slots before and after the noise signal, nor in the comparison of the speed reduction situation and the unknown situation.

Concerning the workload data in general, it can be seen that in the unknown situation in the SuRT condition the workload was reduced more in contrast to the speed situation. This result corresponds to the reduced activity data in this condition.

## 3.3 Correlation of activity in secondary task and mental workload data.

To show the direct interaction between mental workload and the activity data in the secondary task, a Pearson product-moment correlation was computed for the data of the first passed situation. Correlations were analyzed in the different secondary task conditions, in the different situations and in the different time slots per participant.

For the SuRT secondary task, the correlation between the activity data and the mental workload in the speed reduction situations after the noise signal ($r = .48$; $p = .02$) and in the unknown situations ($r = .56$; $p < .001$) was significant. In the CTT task the correlation before the noise signal in the unknown situation ($r = .43$; $p=.03$) was significant as well. None of the other correlations were significant. According to these results, a direct coherence between activity in secondary tasks and workload cannot be shown in general.

## 3.4 Driving data

The driving speed and the distance to the middle of the lane were analyzed to explore if any differences occurred between the situations. Thereby, lateral control as well as longitudinal control were evaluated. For each variable, a repeated ANOVA was computed with three factors: *secondary task* (SuRT versus CTT), *situation* (speed reduction versus unknown situation) and *number of passed situations* (the four passed situations in the sequence a participant had driven through). No main effects or interactions became significant in the driving speed data. This is easy to explain, because driving speed was regulated by a speed control system.

A significant main effect was shown relating the distance to the middle of the lane in the factor *situation* ($F(1,7)=19.88$, $p<.01$). Drivers had a greater distance to the middle of the road in unknown situations. This can be explained as affected by conditions: drivers often had to cross lanes in the unknown situations because of an obstacle – like a broken down car – on their side of the road. Those obstacles were not presented in the speed reduction situations. To sum up, the results of the driving data showed no surprising differences between the conditions. The data are not crucial concerning the basic subject of the current experiment but prove the experimental framework to have worked out well.

# 4 Overall discussion

To evaluate compensative behavior in dual task situations, three relevant factors were identified: driving task, secondary task and mental workload. These factors were analyzed in cross-reference to each other. It was assumed that a driver compensates demands in one factor with adaptations in one or two of the others. Therefore, the focus of this study lay on different properties of the secondary task and the question whether different compensative behavior would be provoked by different kinds of secondary tasks. The hypothesis was that if a secondary task is interruptible without a perceived loss of performance, drivers compensate a demanding driving situation with an interruption of the secondary task, instead of accepting a heightened workload. If drivers perceive a loss of performance due to an interruption of the secondary task, it was expected that they compensate the demands with a higher effort and therefore show a heightened mental workload. It was assumed that these effects especially occur in demanding driving scenarios. Such situations were realized as situations in which the current situation model had to be questioned and the driver did not know what to expect concerning the development of the situation. In these situations, it was tried to provoke a conscious comparison between the current situation model and the perceived and expected stimuli. These processes were expected to produce a higher workload (Krems & Baumann, 2009).

The postulated effects could be shown in this study. As expected, drivers especially interrupted the secondary task in the condition in which they were able to interrupt it without a loss in performance (SuRT) and they were not able to anticipate the further development of a situation (unknown situations). The measured mental workload was also lower in these situations compared to the speed limit situations and to the time span before the cue to the situation was given. In the condition in which drivers could not interrupt the secondary task without lowering the performance (CTT), no difference appeared in the activity data between the two types of situations. Additionally, no difference occurred between the time span before and after the noise signal in the workload data. Participants had to compensate the demands in one factor with another, depending on which adaption seemed to be most adequate. The interaction between the three factors shown in figure 1 has become more elaborated by these results.

The methodological paradigm used in this study appears promising. It was attempted to change the anticipation of drivers by given cues. The resulting behavior was measured in a time slot in which the drivers did not see a critical situation yet, so only their expectations could influence their behavior. Additionally, a relation between the relevant driving situation and the dependent variables was established which helps further understanding dynamic behavior adaptations. Especially the measurement of the mental workload and the activity in the secondary task can give insights of interactions and compensative adaptations. By using the ICA it was possible to measure workload precisely in the relevant time span, because of the high temporal resolution of this method. A second advantage of the ICA is that retrospective errors and subjective biases do not have an influence on the data.

The postulated effects could only be proven for the first passed situation in each condition and situation type. There seems to be a learning effect in the further development of the driving course. When drivers had repeatedly passed situations, they were operating the secondary tasks more and the effect of a lower mental workload could not be measured any longer. A self-evident explanation for this effect is that the participants did not experience the second and following situations as situations in which they could not anticipate further situational development. After having driven through the first situation they had already experienced what happened after the announcement of an “unknown” situation. Because of that drivers did not interrupt the SuRT secondary task anymore after passing the first situation. It seems to be important to differentiate between the data of the first situation and the following. If it is aimed to measure an unbiased and inexperienced “naturalistic” reaction to a situation, it is not possible to repeat a situation. Even if a situation is constructed differently from the first situation, participants probably adapt their behavior according to the first experienced situation.

The correlation between workload and activity in the secondary task was only significant in a few conditions. The reason for that could be interpersonal differences which might have produced a moderating effect. How much workload drivers tolerated before they try to compensate a demand differed between subjects as well as how much performance loss was tolerated without an increased effort (see high data variance). Also the different skills of drivers could have reduced the correlation (the task load remained the same, but the workload differed between drivers). Following these thoughts it seems to be important to measure both kinds of data.

In literature, the methodological focus often lies on the possibility and the consequences of interrupting a task, but not on the degree in which a driver actually interrupts it while driving. The occlusion method, for example, measures the additional task time resulting from an interruption (e.g. Keinath, Baumann, Gelau, Bengler & Krems, 2001). But it is often not measured whether a driver also interrupts a task in such a driving situation. It is possible that the usage of a system does not take more time if it gets interrupted, but drivers do not interrupt this system, because of the perceived loss they expect due to an interruption. This is a safety critical issue because, in consequence, mental workload is heightened and less mental resources can be employed for the primary driving task. For a better understanding of these effects it is necessary to develop a method for a standardized comparison of different secondary tasks regarding the shown interruption pattern in driving situations (see study 3 for a first step towards such a method). Thus, the relation between compensative behavior adaptations and the attributes of a secondary task could be understood in more detail.

# A new approach of measuring activity patters in a secondary task while driving[7].

Abstract

In everyday driving scenarios the operation of a secondary task not always results in a reduction of the driving performance. Drivers seem to adapt their behavior to the demands of an anticipated driving situation. The activity in a secondary task is reduced in a demanding situation and depends (among other things) on the properties of the secondary tasks. A method which aims to evaluate the shown operating interruptions while driving must allow these adaptations and has to measure them at the same time. Additionally, a driver should have the opportunity to anticipate the further driving situations to simulate a realistic driving situation. The modified lane change task setting presented in this study fulfills these requirements. The lane changes were announced by an acoustic signal, but were presented in randomized intervals. In an experiment with 22 participants 4 tasks, which differed concerning their interruptibility, were compared to each other. The data showed significant differences between the tasks and different time spans concerning the activity in the secondary task according to the hypothesis. The presented setting provides a paradigm to test secondary tasks concerning their interruptibility and to evaluate realistic behavior adaptations of drivers.

Keywords: Driver distraction, Task interruptibility; Behavior adaptations

[7]In preparation to submit to *Transportation Research Part F: Traffic Psychology and Behaviour; by* Frederik Platten, Maximilian Schwalm, Josef Krems

# 1 Introduction

Drivers are doing a lot of different things while driving (Dingus et al., 2006). Nearly every driver has talked to a passenger, chosen a music track or changed the air-conditioning's settings while driving. Drivers nevertheless are often able to operate a secondary task while driving (which is the primary task) without provoking hazardous driving situations or even causing an accident. This fact raises the question how drivers manage the demands of a parallel driving and operating situation. Two skills seem to be crucial therefore: to anticipate a situation and to adapt one's own behavior according to this anticipation.

First, drivers are in principle able to anticipate the further development of a driving situation (Rauch et al., 2009). Therefore drivers have to percept relevant stimuli, comprehend their meaning and project the future status of a situation (Endsley, 1995b). Drivers are expected to compare currently perceived stimuli with their situation model of the current driving situation. A situation model can be defined as the generalized knowledge of a specific situation configuration. This knowledge depends on memories stored in long term memory. It contains stimulus configurations, rules and the adequate actions in this type of situation (Krems & Baumann, 2009). By activation of the relevant situation model in a driving task, the drivers can generate specific expectations about the future states of the driving situation. In a predictable situation, drivers have the opportunity to adapt their behavior in advance. It is expected that a driver is able to perform multiple tasks at a time if he or she adapts his or her driving and operating behavior to the demands of a situation. The proper action for a given situation is expected to be stored in the long term memory (Ericsson & Kintsch, 1995) and to get activated by perceived stimuli or triggers (Norman & Shallice, 1986). A proper action in an anticipated demanding situation could be to adapt the activity in secondary tasks to focus mental resources on the driving task. Following this assumption, drivers are expected to reduce the activity in a secondary task, if they expect that the demands of that situation will rise in the near future (see study 1 and 2). Drivers who are typing a destination into a navigation system are supposed to interrupt this operation, for example, if they expect to approach a danger spot in the next few seconds.

By anticipating the further driving situation and by regulating the activity in different tasks according to this anticipation, it quite often seems to be possible to drive without accidents and to perform multiple tasks at the same time, even though mental resources are limited (Kahneman, 1973; Pashler & Johnston, 1998). Different factors are expected to play a relevant role if drivers regulate their activities successfully in a demanding situation: The driving situation itself, driver traits and specific attributes of a task interact thereby with each other and influence the shown behavior (e.g. Fuller, 2005). Involvement into a task, joy of use, personal preferences and other effects (e.g. cognitive capture) are also expected to be important factors, to mention just a few with focus on the driver (e.g. Michon, 1985). But the underlying influencing factors and the direction of the effects between them are yet largely unknown (Noy, Lemoine, Klachan & Burns, 2004).

In this study the focus lies on one of the factors that are supposed to play a significant role in this complex effect and interaction structure: the secondary task. The present experiment focuses on one attribute which seems to be particularly important: the perceived loss of performance that arises if a driver operates two tasks (driving + another task) at the same time and switches between them. It is well known, that switching between driving task and secondary task produces so-called switching costs (Rogers & Monsell, 1995), especially if the tasks are complex (Rubinstein, Meyer & Evans, 2001). It is assumed that switching costs occur, because after switching from one task to another, an operator has to reorient to the new task which takes additional resources. Goal shifting and rule activation demand a control executive (Rubinstein et al., 2001). The central executive proposed by Baddeley (e.g. 2003) is a flexible cognitive system which is responsible for the control and regulation of different cognitive processes. To translate the general findings to a driving context, this means that switching between the driving and a secondary task can occupy resources that would be needed for driving itself.

Switching to and operating a secondary task in a demanding context with high time pressure (as it often occurs in automotive context) is expected to cause an assignment of limited resources to the driving task. If drivers reduce their activity in a secondary task, they have more resources available for the driving task. Following that, it is highly relevant in which situations and tasks drivers reduce their activity. It could be shown that drivers will likely interrupt a secondary task and focus on the driving task in a demanding situation if a reduction causes no disadvantage, more precisely, no reduction in the perceived performance in this task (see study 1 and 2). In contrast, if drivers expect a performance loss by interrupting their secondary task they will continue operating and try to manage both tasks simultaneously. A task which produces a high level of perceived loss of performance in an automotive context may for example be a timeout function in an infotainment system. This is expected to happen because the absence of an entry often leads to a change of the menu position to a previous position (in most cases the main menu). Due to that, the operator has to start again at the beginning of the menu dialog and so he or she is likely to try to finish the task before the operation is timed out (for example typing a destination into a navigation system). Thus, the operator perceives a loss of performance if the task is interrupted, because the timeout function will enforce starting again. In order to avoid this, operators may continue to operate the task even if this reduces their driving performance. In line with this statement, it could be shown that in hazardous driving situations the activity in a secondary task was not reduced as much if the perceived loss of performance in this secondary task was higher, compared to the situation in a secondary task in which the reduction of the activity had no negative outcome to the performance (see study 2). To sum up, drivers allow a secondary task to occupy more resources if they expect a lower performance in this task due to an interruption.

In a naturalistic driving study, it could be proven that in nearly 80% of crashes driver distraction played a relevant role (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). One important factor to successfully manage different tasks at the same time is to choose the right moment to change activity and the right level of activity at any given time. If the activity in a secondary task is reduced too late, too shortly or too little regarding the situation, drivers can be occupied too long by this task, which can drastically reduce driving performance (see also Antin, 1993).

Because of the importance of an adequate activity regulation in a secondary task, it is relevant to measure if this activity is reduced in the moment a driver anticipates an upcoming driving event, or if the driver is continuously operating the system. An approach that can be used to measure such adaptations independently from specific driving situations (as used in study 1 and 2) is to be developed in this study. Specific driving situations used in studies on driving behavior are sensitive even to small changes in the experimental setting. The perception of such a situation can be influenced for example by the used driving simulator or the used virtual environment (e.g.: how many distracting elements, for example other pedestrians, are implemented into the scenery). Therefore, an approach should be developed in which most influencing variables can be controlled. Nevertheless, the possibility to anticipate driving events and to adapt to them should be still given to the participants. Several methods are discussed in the later paragraphs and a new approach is presented afterwards.

## 1.1 Measuring Activity in a Secondary Task while Driving

Several guidelines and self commitments point out that the interruptibility of secondary tasks is one important quality and safety factor for in-vehicle systems (e.g. European statement of principles on human-machine interface (Commission of the European Communities, 2008) or the guidelines of the Alliance of Automobile Manufacturers (2003)). Different methods are used to measure the interruptibility of vehicle systems. One well known method is the occlusion method (Gelau, Henning & Krems, 2009; ISO 16673, 2007; Keinath, Baumann, Gelau, Bengler & Krems, 2001; Krems, Keinath, Baumann, Gelau, Bengler, 2000). Using it, participants wear glasses which simulate glances to the street. In 1.5 second lasting time spans, the lenses of the eyeglasses are nontransparent and for 1.5 seconds the lenses are transparent. Those time spans are alternating. To measure the effect of the nontransparent time spans (the time a driver would look in a driving situation on the street) the index R' is calculated. Therefore the Total Open Shutter Time (TSOT) is measured. This measurement is defined as the Total Task Time needed to finish a task (TTT), minus the time glasses are nontransparent. By dividing the TSOT by the time that is needed to finish the task without active glasses (baseline), the index R' results (Gelau & Krems, 2004). Thereby R' indicates the interruptibility of a task (Noy et al., 2004). An R' value above 1 indicates a prolongable influence of the interruption on the time to finish the task. The higher the deviation from 1, the stronger is the effect. If R'=1, an interruption has no negative effect to the needed time to finish the task. The focus of this method lies on the visual demands of a secondary task. Nevertheless it is also used to measure of the interruptibility of a task (Noy et al., 2004; McFarlane, 2002). An advantage of this method is that it is easy to use and can be implemented nearly everywhere. According to the ISO norm all use cases have to be repeated five times with and without glasses.

Concerning the measurement of the interruptibility of a secondary task, it must be distinguished between the empirically shown changes in the input activity to the secondary task and the possible interruptibility of a task in a driving situation. The shown changes in the activity should be influenced by the overall perceived loss of performance by interrupting the task. The occlusion method measures the necessary time for executing a task. It does not show if the activity level is adapted at all nor if the activity is adapted with a proper timing in demanding situations. In this method, drivers are not able to adapt their behavior according to the situation but have to react passively to the opening times of the glasses.

To analyze behavior patterns in a more realistic traffic-like setting than the occlusion method does, a measurement paradigm is needed that enables a driver to anticipate the further driving situation and that allows the measurement of the resulting behavior adaptations. In the lane change task (LCT) a driving task with its basic demands is simulated (Mattes & Hallén, 2009). Participants are driving on a simulated street with three lanes. Drivers have to change the lane periodically. Signs beside the street indicate which lane should be chosen by the driver. The driver has to perceive the sign, react to it by maneuvering to the indicated lane and then stay in this lane. The task is a standardized driving situation in which important parts of the normal driving behavior are simulated. Nevertheless, some methodical downsides can be deduced. The prompts for lane changes occur in nearly periodical time spans (7-9 seconds), so that participants can precisely anticipate the next lane change and adapt their behavior to it (Schwalm, 2009). This is not typical for real driving tasks in which demands occur erratically. Otherwise, if the signs would appear completely randomized in the LCT, it would not be possible for the driver to anticipate the further driving situation. In this case a driver could not use any of the compensative strategies described above, because these rely on the possibility to anticipate. Therefore, an adapted LCT version is used in this study. It gives a driver the chance to anticipate upcoming situations, but not in a predictable regularity.

Following the theoretical framework described above, it was expected that task input activity would be less reduced (even in critical situations) in a secondary task which produces a high loss of perceived performance if interrupted than in a task which only produces a low or no loss of perceived performance if interrupted. This hypothesis was expected to be testable with the adapted LCT setting, but not with an occlusion setting, because in this setting the degrees of freedom to adapt to a task are limited (the transparent time spans of the occlusion glasses are determined to 1.5 seconds). The occlusion method was used in this study to compare the new setting to an established, standardized method.

The goal of this study was to try out a new paradigm to measure the interruptibility of an IVIS (In-Vehicle Infotainment System) in an early stage of its development process. In a situation in which a driver anticipates a demanding driving situation, a better interruptibility of a secondary task should lead to a greater reduction of the activity in this task.

# 2 Method

## 2.1 Participants

22 participants took part in this study, five of them were female. The average age was 31.2 years (SD: 6.9; range: 24 to 46 years). All of the participants had a valid driver's license (averaged since 12 years). The average mileage was about 10 000 kilometers per year. Participants all had normal or fully corrected to normal visual acuity. Most of them were BMW Group employees from different departments, and none were paid for their participation.

## 2.2 Driving task

A modified lane change task (LCT, compare to Mattes & Hallén, 2009) was used in this study to fulfill two requirements: first, the task should allow the possibility to anticipate (at least in parts) the future driving situation. Second, the anticipatable driving situations should not be completely predictable. Therefore the LCT was adapted as follows: The orders to change the lane were presented randomized, but these orders were announced by a sound. Thereby participants were able to anticipate the upcoming order. The information that the lane should be changed in the next few seconds was given by a noise signal, but participants did not know which lane they had to change to. From the moment of the noise signal (cue) participants were expected to adapt their operational behavior in the secondary task. The time span between the noise signal and the order to change the lane was varied between five and seven seconds, to make the task more realistic than the LCT (in a real driving situation a cue to a relevant driving action is not always perceived in the same time span before). The task setup is shown in figure 1. Instead of the signs next to the road (for a comparison see Mattes & Hallén, 2009), three red light diodes were used to indicate the lane which the participants should change to. This was done only because of technical reasons (the signs next to the road cannot be moved within the LCT software). The light diodes were placed on the monitor and gave the light signals to change the lane. The noise signal lasted 0.7 seconds and the light switched on for 1.7 seconds. For the data evaluation, the position of the instructed lane changes (the noise signals) were recorded per markers into the log files of the LCT software. These positions were afterwards used to generate new setting files for the LCT analysis software. All tasks were repeated once to minimize the variance. This part of the study took about 15 minutes; the complete study approximately one hour.

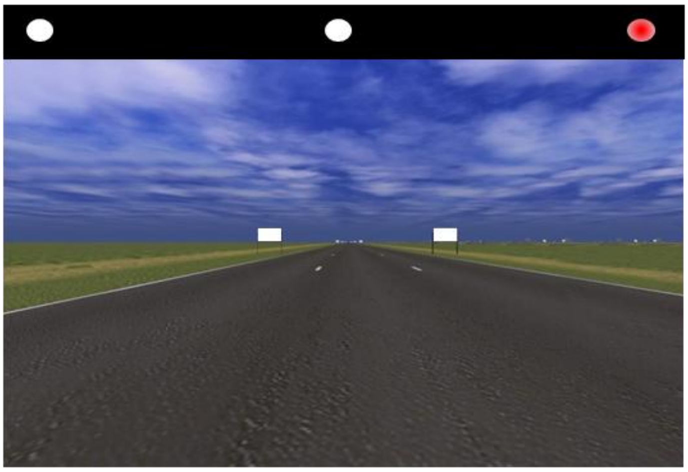


**Figure 1:** The setup of the modified lane change task (here the right lane should be chosen).

## 2.3 Secondary Tasks

To evaluate two extremely different tasks according to the consequences of interrupting them, the Surrogate Reference Task (SuRT; Mattes, 2003) and the Critical Tracking Task (CTT) were used. Reducing the activity in the CTT task caused a direct loss of performance in the task whereas it did not in the SuRT task. Additionally, a more proper task for the driving context (called “HardListing”) was constructed to simulate a visual search in a list of contacts with and without a timeout.

### 2.3.1 Surrogate Reference Task

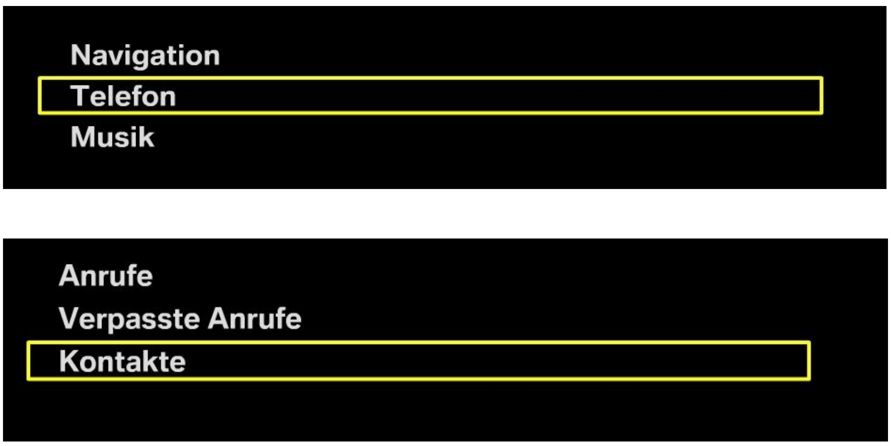
In this task the participants had to find a target circle between 50 distractor circles. The radius of the target was larger than the other circles. The relationship between distractor size and the target was 100/150. A grey cursor had to be moved by two arrow keys (left and right) and the position had to be confirmed with a third arrow key on the steering wheel (down). Ten positions were possible for the cursor. All screens were independent from each other. In this study, participants were instructed that the total number of solved tasks was not central, so that a reduction of activity was not expected to result in a perceived performance loss.

### 2.3.2 Critical Tracking Task

The participants had to keep a horizontal bar in the middle of the display by using the arrow keys up and down on the steering wheel. The bar was moving faster when it moved further away from the middle of the screen (with a logarithmical ascending speed, lambda=1). The moving direction of the bar (up or down) was random. If the activity in this secondary task is reduced the performance decreases directly, due to the permanent movement of the bar.

### 2.3.3 The “HardListing” secondary task

In this task, the participants had to find a specific contact address (for example “Monika Abel, Braunweg 21, Koeln, ber” see figure 2). The task was an in-house development of the BMW Group. It was programmed for this experiment to realize a visually demanding task that was highly adaptable. On the first screen, the item “telephone” and on the second screen the item “contacts” had to be chosen (see figure 2a: “Telefon”, 2b: “Kontakte”). Afterwards, a list with contact addresses appeared. Figure 2 shows the three types of screens. Each contact address (one line on the screen includes one address) contained one name, one surname, a city, a street with a house number and the abbreviation “ber.” (german “beruflich”) for relating to business and “priv.” (german “privat”) for private contacts. These different attributes of one address item were presented in randomized order. In this experiment, a standard BMW iDrive controller was used to scroll through the list (turning the controller moved the yellow cursor down). Every list consisted of 55 addresses (by moving the cursor down, the other items got visible). To choose the right item, the controller had to be moved to it and the controller had to be pushed down to select it. To minimize memory effects, three different lists were used, with 15 different targets each.




a)

b)

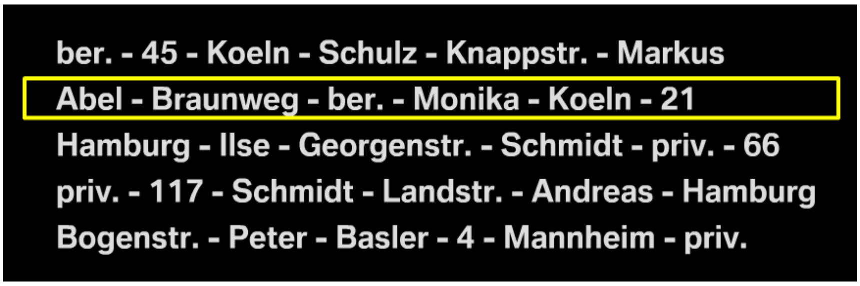
c) 


**Figure 2:** Examples for the three different screens of the “HardListening” secondary task. Figure 2c shows a list of five different contact addresses.

Two different versions of this contact address system were used, one version with an implemented timeout function and one without. In the timeout version, every time users did not perform any action for five seconds (this time span was assessed as realistic by an expert rating) in this secondary task, the system was reset to the beginning of the menu (see figure 2a). When users then got back into the item list (figure 2c), the curser was still on the same item as before the timeout was triggered. Thereby, users did not have to scroll through the whole list again. All secondary tasks were presented on a screen next to the screen which showed the adapted LCT. The experimental setting is shown in figure 3.

## 2.4 Occlusion method

As described above, in the occlusion method glasses were used which switch every 1.5 seconds from transparent to nontransparent to simulate glances to the street. All use cases (see “HardListing task”) were repeated five times, with and without the glasses on following ISO 16673 (2007). This part of the study took approximately 30 minutes.

**Figure 3:** The used setting is shown here. The EyeLink2 eyetracker system, which was used to record the workload data, is also visible.

## 2.5 Setting & Design

The experiment took place in the BMW usability labs. The participants trained all secondary tasks, the driving task and the combination of both tasks simultaneously. Afterwards, participants completed the two parts of the study: Part 1 was driving the adapted LCT course and simultaneously operating the secondary tasks and part 2 was the occlusion condition. The two parts and the tasks within one part were presented in a randomized order.

## 2.6 Recorded data

Different types of data were collected to compare the standard ISO occlusion method with the new setting. Therefore the occlusion data (needed time to finish tasks) of every participant were recorded. The shown activity in the secondary task and the driving data were recorded in the LCT part. Additionally, the subjective data were measured by the questionnaire Driving Activity Load Index (DALI; Pauzié & Manzano, 2007). This questionnaire, specifically designed for a driving context, contains 7 dimensions concerning the subjective activity load while driving. To measure the workload of the participants the Index of Cognitive Activity (ICA) was used. The ICA is a physiological method to measure mental workload. The human pupil reacts to mental demands through changes in its size (Hess & Polt, 1964). For the compilation of the ICA the short and fast changes of the pupil are measured per second. The ICA seems to be a good indicator of mental workload in demanding and vivid environments. The range of the index is 0 to 1. The higher the value, the higher is mental workload. The index was used and approved in an automotive context with basic driving tasks by Schwalm (2009).

## 2.7 Analyzed time span

To analyze the effects of the cue (noise signal) to a demanding driving situation (in this study the lane change) to the drivers' behavior, different time spans were analyzed: before and after the noise signal (see figure 4).

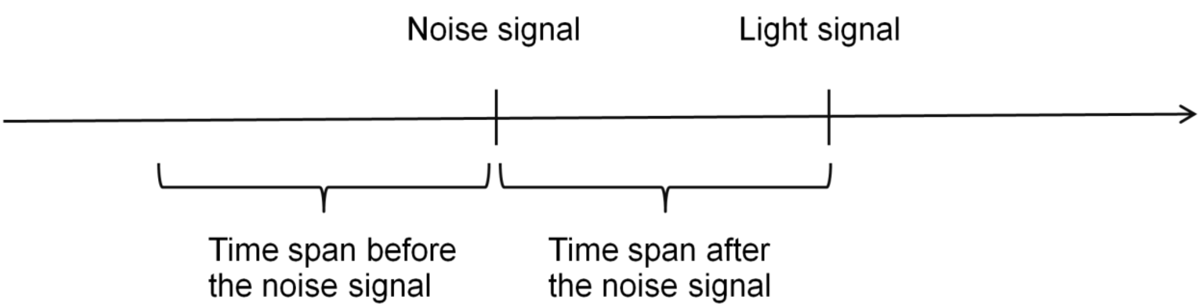



**Figure 4:** The analyzed time span before and after the noise signal.

The length of the analyzed time span before the noise signal was calculated according to the time span after noise signal. It varied between five and seven seconds so in case of a five second span, data of these five seconds were averaged and if the signal was given seven seconds before the light signal, seven seconds were averaged.

# 3 Results

## 3.1 Activity in the secondary task

At first the activity data is compared in the different “HardListing” tasks and after that between the SuRT and CTT task. Additionally to the standardization of the different time slots (see above), the data were z-standardized within the participants over all situations and conditions.

### 3.1.1 Comparison between with and without a timeout in the “HardListing” task

First of all, the differences in the operating activity in the “HardListing” task were compared between the different conditions and time spans. In a 2 (*point in time*: before versus after the noise signal) x 2 (*timeout*: with timeout versus without timeout) ANOVA, the factor *point in time* got significant (F (1,15)=5.13; p=.03), as well as the factor *timeout* (F (1,15)=8.63; p=.01). The activity was lower after the signal and the activity was lower in the condition without a timeout. The data are shown in figure 5. The interaction between the two factors did not get significant. In a Bonferroni post hoc test, the difference between the two systems (with and without timeout) was not significant for the time span before the signal, but for the time span after the signal: In the condition without a timeout, the activity was much lower (p=.001, Cohens *d*=.46). The activity difference between before and after the signal also got significant in the condition without a timeout (p=.01, Cohens *d*=.45), but not in the condition with a timeout.

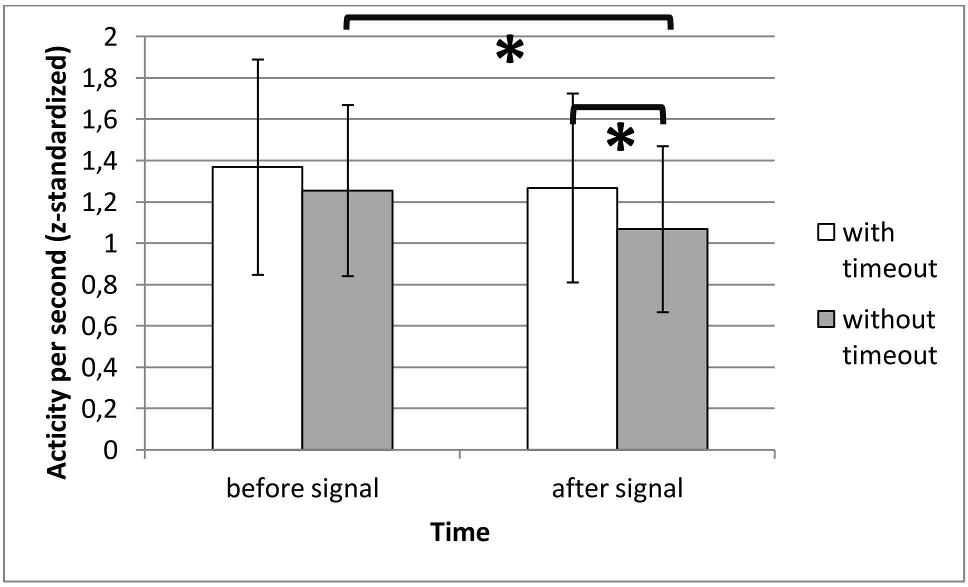



**Figure 5:** The activity per second in the two conditions of the "HardListing" task with their standard deviations. The significant differences in a post hoc test are marked with an *.

### 3.1.2 Comparison between the SuRT and the CTT task

The difference of a system with and without a timeout function was also explored on a more abstract level using the two standardized secondary tasks SuRT and CTT. In a 2 (*point in time*: before versus after the noise signal) x 2 (*secondary task*: SuRT versus CTT) ANOVA, the factor *point in time* got significant (F (1,14)=45.84; p<.001), as well as the interaction between *point in time* and *secondary task* (F (1,14)=12.71; p<.01). After the noise signal, the activity was lower, especially in the SuRT task (see figure 6). The factor *secondary task* did not get significant. In a post hoc test the difference in the SuRT condition between before and after the signal got significant (Bonferroni post hoc test: p<.001, Cohens *d*=2.00). In contrast, there was no significant difference in the CTT condition. The difference between the two tasks only got significant after the signal (p<.001, Cohens *d*=.92).

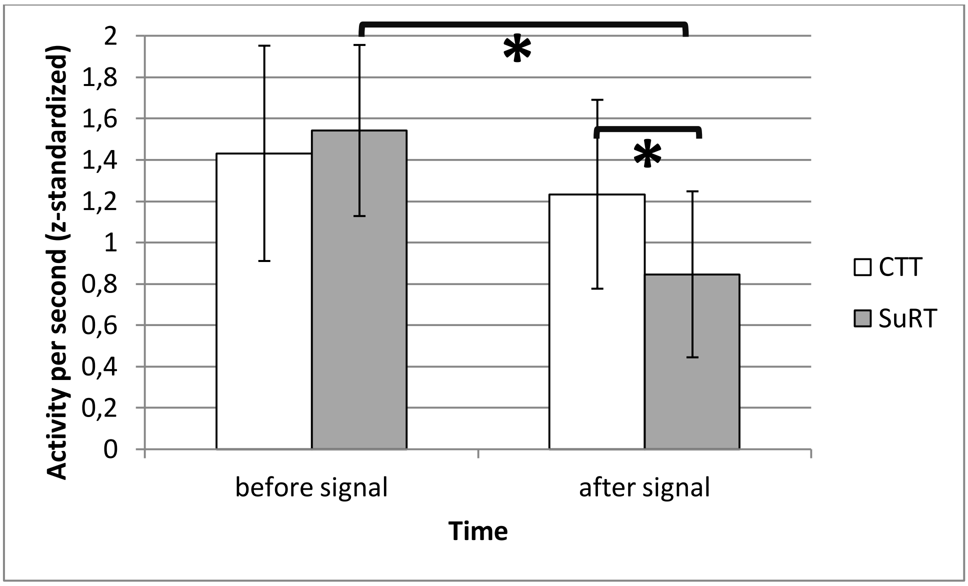



**Figure 6:** The activity per second in the SuRT and CTT task with their standard deviations. The significant differences in a post hoc test are marked with an *.

Summarizing the activity patterns in the tasks investigated, a clear difference between the tasks can be shown. In the SuRT and the “HardListing” task without a timeout a reduction of the input activity got obvious after the signal compared to the time span before the signal. No reduction was shown in the CTT and the “HardListing” task with a timeout function.

## 3.2 Index of cognitive activity

All of the ICA data were z-standardized within subjects according to Schwalm (2009) and summed up for the relevant time spans according the processing of the activity data.

### 3.2.1 Comparison between a system with and without a timeout in the “HardListing” task and baseline data

In a 2 (*point in time*: before versus after the noise signal) x 3 (*secondary task*: with timeout versus without timeout versus baseline (no secondary task)) ANOVA, the factor *point in time* got significant (F (1,18)=5.61; p=.02). Workload was slightly higher after the noise signal, as it is shown in figure 7. The factor *secondary task* got significant with (F (2,36)=56.68; p<.001) as well. Workload in the baseline condition was lower before and after the signal compared to both secondary task conditions.

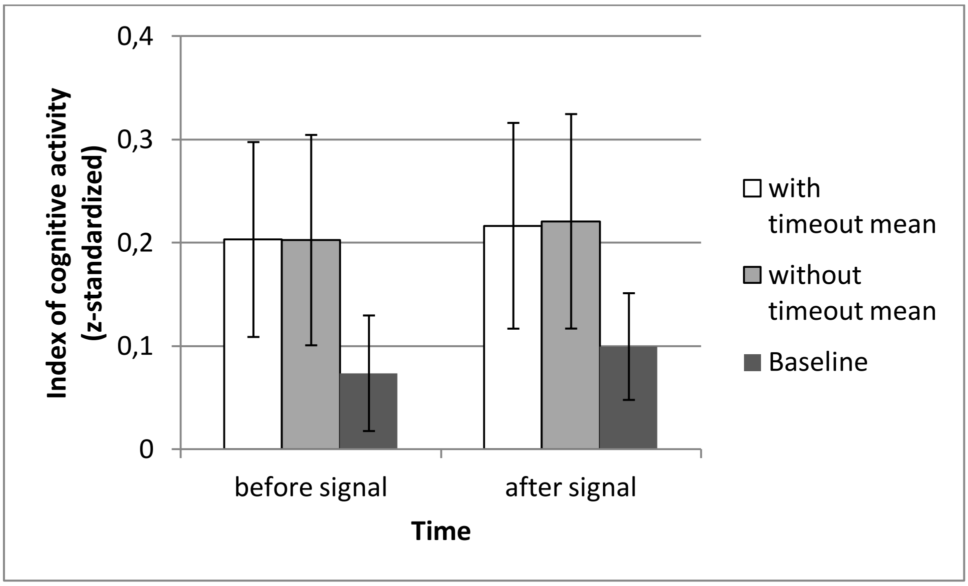



**Figure 7:** The data of the workload index ICA in the two conditions of the "HardListing" task and the baseline with their standard deviations.

### 3.2.2 Comparison between the SuRT and the CTT task and the baseline data

In a 2 (*point in time*: before versus after the noise signal) x 3 (*secondary task*: SuRT versus CTT versus baseline) ANOVA, the factor *point in time,* as well as the factor *secondary task* and the interaction of these two factors got significant (*point in time:* F (1,17)=4.59; p=.04; *secondary task:* F (2,34)=103,23; p<.001; interaction*:* F (2,34)=6.40; p<.01;). Workload was always lower in the baseline conditions, before and after the signal (significant Bonferroni post hoc test). The results are shown in figure 8.

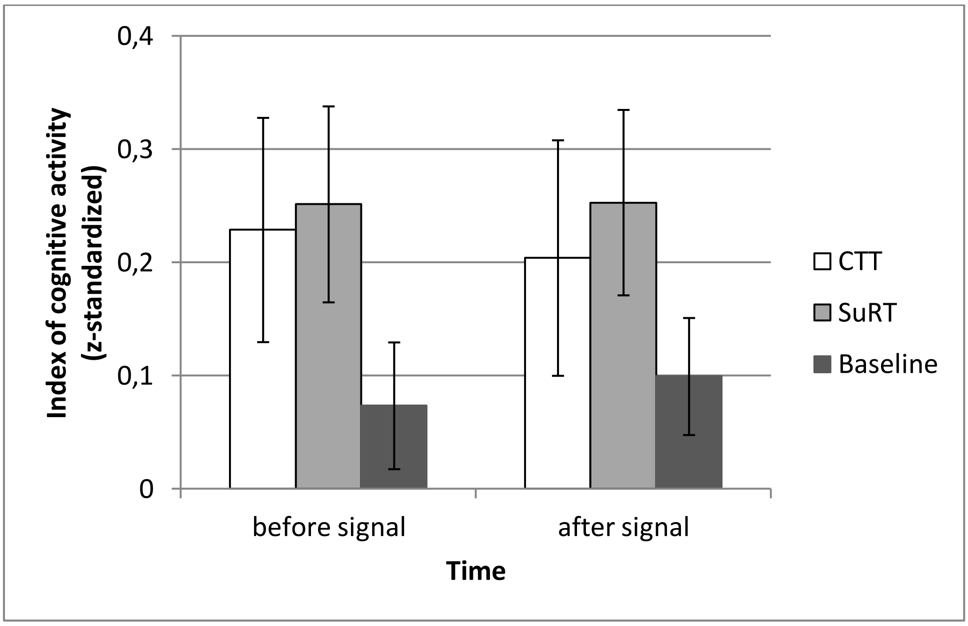



**Figure 8:** The data of the workload index ICA in the SuRT, CTT, and baseline task with their standard deviations. All differences were significant in a post hoc test.

The workload data showed a clear effect between the baseline and the other conditions, but no different patterns before versus after the signal between the different tasks.

## 3.3 Subjective data

The data of the questionnaire DALI for a comparison between a system with and without a timeout in the “HardListing” task are shown in figure 10. In a 2 (*timeout*: timeout versus without timeout) x 2 (*items*: the seven different items) ANOVA, the difference between the two systems got significant, as well as between the items and the interaction between the factors (factor *timeout*: $F(1,13)=5,68$; $p=.03$; factor *items*: $F(6,78)=7.91$, $p<.001$; interaction: $F(6,78)=5.17$, $p<.001$). As shown in figure 10, the major distinctions could be seen in the items that measure the produced stress and the time pressure of the operated task. The “Hard Listening” task produced only more stress and time pressure when a timeout function was present.

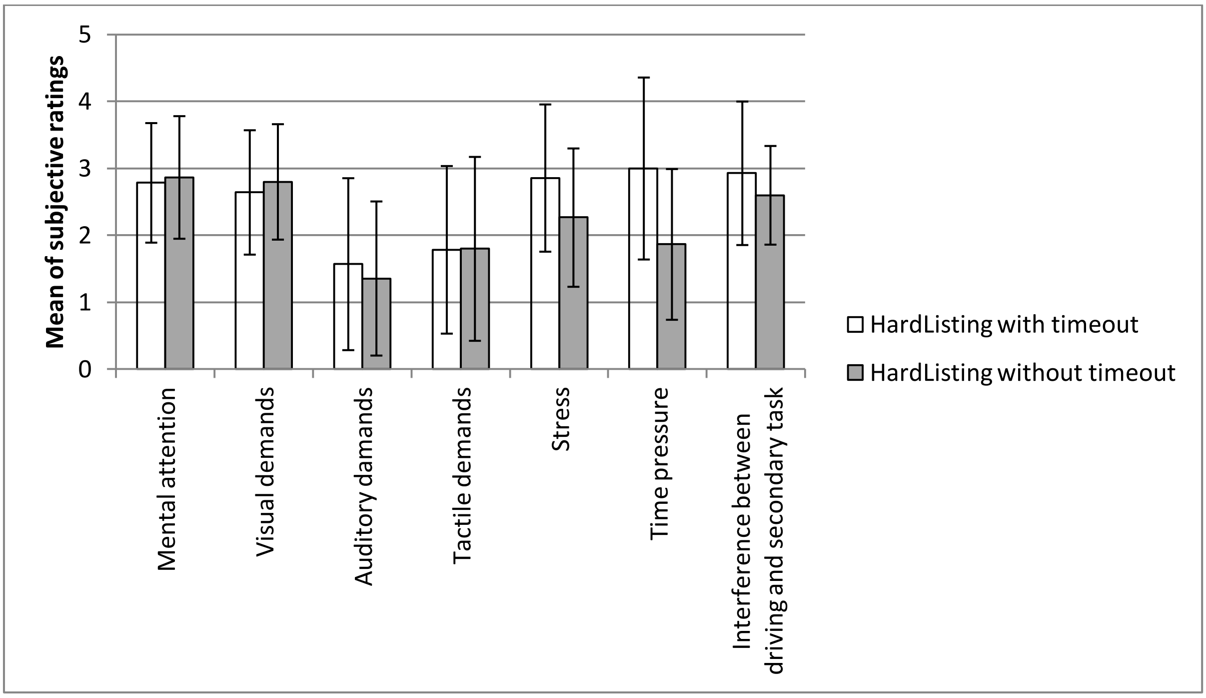



**Figure 9:** The data of the questionnaire DALI, with the range from 0 to 5 (0=lowest demand). The standard deviations are also plotted.

## 3.4 Data of the driving task

An ANOVA with the factor *secondary task* ("HardListing" task with and without a timeout, SuRT task, CTT task and no secondary task (Baseline)) showed no differences in the mean deviation of the optimal line ($F(4,65)=4.59$; $p>.05$). The participants did not show a different performance whether they operated any secondary task while driving or not. It also did not make any difference what kind of secondary task they operated (see figure 9).

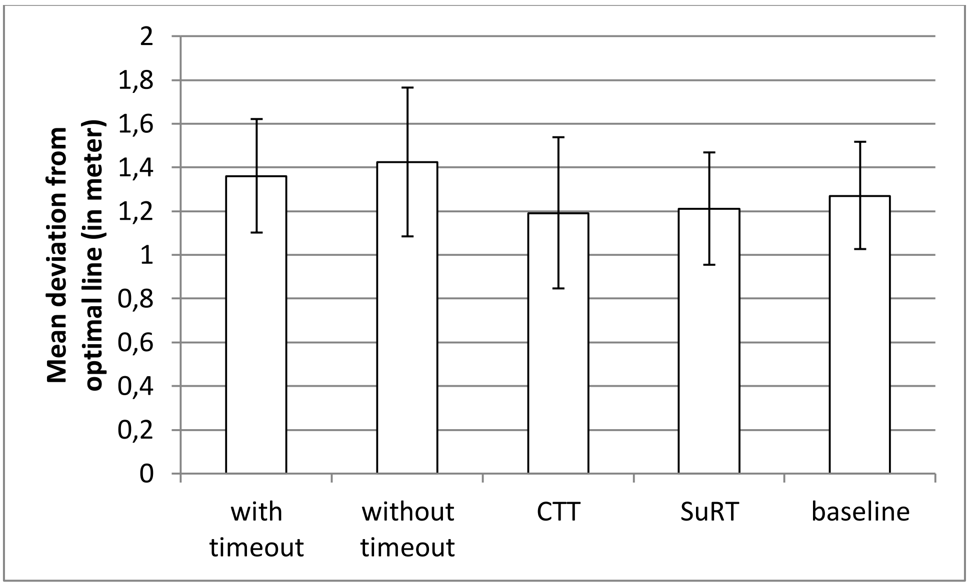



**Figure 10:** The driving performance in the modified lane change task with their standard deviations.

## 3.5 Data of the occlusion method

The time needed for the "HardListing" task for the condition with the glasses on as well as for the condition without the active glasses is shown in figure 11. The R' value was 1.45 for the condition with an implemented timeout function. Without a timeout function, R' was 1.68. A tendency could be shown for a worse interruptibility in the condition without a timeout function. In a t-test between the two conditions, no significance could be shown. To sum up, no significant differences could be shown between the different conditions with the occlusion data contrary to the results in the adapted lane change setting. This discrepancy will be reviewed in detail in the discussion.

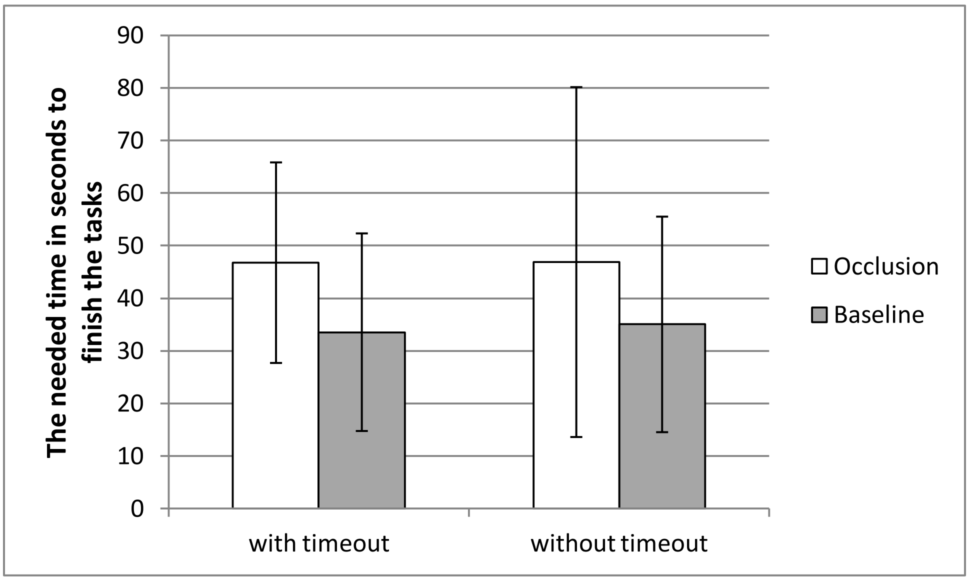



**Figure 11:** The data of the occlusion method, in the two conditions of the "HardListing" task with their standard deviations. In the Occlusion condition, the glasses were nontransparent for 1.5 seconds; no glasses were used in the baseline condition.

As the SuRT and CTT task were operated continuously without having a fixed ending or goal, respectively, the occlusion method did not produce useful data. Due to this task design, the data of the occlusion method are not presented here.

## 3.6 Correlation between the R' values and the activity reduction

To compare the measured values of the occlusion method and the new setting directly with each other a correlation was computed. Therefore, the activity reduction index was calculated (activity per second before the cue (noise signal) minus activity per second after the cue). The correlation over both "HardListing" tasks (with and without a timeout) between the R' values and the activity data did not get significant (p=.27). As no correlation could be shown, the two indices seem to measure different aspects of the interruptibility construct.

# 4 Discussion

A new paradigm to evaluate the effect of specific properties of an IVIS to the operating behavior while driving was presented in this study. The focus lay on the shown activity in a secondary task when a demanding driving situation was anticipated. The central role of anticipation while driving has been pointed out in several studies (e.g. Krems & Baumann, 2009; Rauch et al., 2009). The reduced activity in a secondary task is central for workload reducing behavior adaptations, which allow drivers to drive and operate a secondary task without a critical reduction of the driving performance (see study 2). Therefore, a setting was constructed in which drivers could anticipate further driving situations, which were presented in a variable time interval. Especially the shown operating activity, before and after a given cue, was compared between different secondary tasks.

The activity in the secondary task “HardListing” (find a specific address item in a list) decreased after the cue, but only in the condition with no implemented timeout the difference to the activity before the cue was significant, as hypothesized. In the condition of the “HardListing” task with a timeout, as expected, no difference between the time span before and after a cue was shown. It can be concluded that no compensative behavior was shown in the secondary task because of its type. In the SuRT task (easily interruptible without a perceived performance loss), an activity reduction could also be shown after the signal, but not in the CTT task (interruption causes a perceived performance loss). The known effect of anticipating the further driving event and the corresponding reduction of the activity in the secondary task could thereby be shown in a basic setting. The effect was also shown with the same tasks (SuRT and CTT) as used in study 2. Additionally, these effects could be proven in the new “HardListing” task which is a more natural task and comparable to a typical visual search task in an IVIS. Taking all evaluated secondary tasks into account, it can be concluded that the participants reduce their activity in a task if they can do it without a perceived drop in performance when they anticipate a demanding driving situation.

Distinct differences between conditions with secondary tasks and baseline were measurable in the workload data. Before and after the cue, the baseline workload was much lower than during the operation of any secondary task. This finding can be explained by the additional demands of secondary tasks in contrast to only operating the single driving task. The Workload also increased after the given cue in the baseline and the “HardListing” condition. After a cue to the situation was given, the drivers had to check at what time and on which lane they should drive. There were no significant differences between the two conditions with and without timeout function in a post hoc test. Maybe the differences between the conditions were not high enough to produce a significant difference concerning the workload data. Here, the lower demands of a driving task (the used modified LCT) compared to a real world situation or a complex driving simulator setting could have led to a lower overall workload and thereby the differences between the experimental conditions did not get significant. The participants maybe did not have to increase their workload onto a high level in this setting therefore. The subjective data support this explanation. Concerning the mental, visual, auditory and tactile demands, the data showed no difference between the conditions, as well as the measured interference between the driving and secondary tasks. All data were within the middle of the scale. In the “HardListing” task with a timeout function only the overall time pressure and stress was higher. This can be explained by the parallel operating and lane changing situation in the condition with a timeout function.

The driving data did not show any differences between the different tasks and conditions. Even the difference to the baseline (no secondary task) was not significant. An explanation for this is, that it is possible for drivers to anticipate and regulate their activity in the secondary task so precisely in the used modified LCT setting, so that no significant drop in performance could be measured.

In the occlusion method the difference between the conditions with and without a timeout in the “HardListing” task did not get significant as well as the correlation between the activity data and the occlusion data. The reason for that could be that the occlusion method just measures what consequences a reduced activity has for the time needed to finish a task and not the currently shown operating behavior. But what differs between the systems is the subjective estimation of the consequences of a reduced activity. Thus, the drivers reduced the activity in the system without a timeout more likely in a driving situation.

In the modified LCT task (for the original LCT setting see Mattes and Hallén, 2009), the participants are allowed to regulate their operating behavior on their own and show a compensative activity reduction in the timeout condition thereby. In the occlusion method this is not possible (Gelau & Krems, 2004), because the timing of the transparent and nontransparent time spans is defined by the method itself. Following that, a new adapted LCT task was used in this study. The shown activity in a secondary task before and after a cue to a demanding situation can be compared. Thereby, two disadvantages of other ways of measuring the effects of IVIS to the operating behavior can be avoided. At first, the activity data are only influenced by the expectation of the driver. Drivers do not have to change the lane or react to a driving event in the measured time span. Thereby, no confounding factor (for example the tactile demands while steering) have an influence. Additionally, the paradigm is relative robust against different input base rates, because the activity is compared within one system (before and after the cue).

To develop the described paradigm to a standardized method, several more requirements have to be fulfilled. As a first step the method should be designed easily and efficiently to use. Concerning these demands the used setup achieved the demands. The participants drove just one minute in most of the cases and only one repetition was conducted. The instruction and training phase were easily to understand and took just a few minutes. Nevertheless, the relevant effects could be shown. As a second step, a reliable and valid index which indicates the interruptibility should be established in future studies. A reasonable statistical value seems to be the difference between the activity before and after a shown cue to a demanding driving situation. Furthermore, it should be controlled how much the reduction of the activity after the noise signal depends on the specific secondary task and the base rate of activity and inputs needed. Following that, different secondary tasks with different attributes should be tested in this setting. Also the impact of different instructions to the secondary tasks should be evaluated. In addition, checking the reliability and the validity by comparing different methods should be a central concern in further studies.

# General discussion

In this chapter, a short summary of the background and chosen approach in this thesis is given. To continue, the empirical findings are summed up for the three conducted studies and their implications are discussed. Then, the advantages and disadvantages of the used methodology are discussed. Finally, a suggestion for future research is given.

## 1 Background and chosen approach

In this thesis the behavior of drivers who are operating a secondary task while driving was analyzed. From the existing literature two constructs could be derived that are central for an analysis of such situations. Firstly, anticipation seems to play a key role for an adequate selection of action in dynamic situations (Endsley, 1995b; Baumann & Krems, 2007). Additionally, mental workload was identified as the critical resource in demanding situations. Mental workload is a limited resource (Kahneman, 1973; Pashler & Johnston, 1998) and operating different tasks at the same time, minimizes available mental resources (Rubinstein, Meyer & Evans 2001). Adapted to a driving context this means that for safe driving it is highly relevant for drivers to assess their actual and anticipated workload together with an appropriate selection of the right moment to change activity and to select the right level of activity in a secondary task. Following that, the regulation of one’s own workload level by adapting operating behavior seems to be an important skill in order to manage difficult driving situations, and it should be evaluated in a proper setting.

In all the studies’ analyses, it was attempted to look at the data of each factor (driving task, secondary task, or mental workload) in temporal relation to the two others. Knowing in what kind of a driving situation the driver is, if the secondary task is operated, and how high the workload is in this time span, can lead to interesting and detailed insights. Therefore, in all of the studies the development of the shown behavior was analyzed depending on the particular, relevant events in time in all different factors.

## 2 Summary of findings

In all three studies a setting was chosen in which a driving situation was simulated and a secondary task had to be performed in parallel. In the first study the scenario contained complex driving situations and drivers were instructed to drive and operate a realistic IVIS system as they would do on a real road. Thereby dynamic compensative operating behavior was shown: when drivers were informed of a hazardous driving situation, they reduced their operating behavior and adapted their speed. This indicates that drivers anticipate the further development of a situation and that they adapt their driving and operating behavior to it. Drivers have and use several options to adapt to anticipated events. The reduction of speed is one effective and often used possibility (for example Pohlmann & Tränkle, 1994). Drivers reduced speed in a moderate way if they were informed of the upcoming event. After passing the critical situation they speeded up again and started to operate the secondary task again.

The close relationship between driving situation, driving behavior, operating behavior in a secondary task and mental workload already became obvious in the first study. Driving behavior and operating behavior were adapted in parallel when participants were informed about an upcoming hazardous situation (with a small temporal offset, first an adaptation of the activity took place and after that a speed reduction).

To analyze the effect of a changed operating behavior, minimizing the variation in the driving variable was attempted. Therefore a speed control system was used in second study. Nevertheless a setting was chosen that simulates complex driving situations. The influencing factors in the secondary tasks (subjective preferences, joy of use while using an IVIS) were also reduced, resulting in two basic tasks being chosen (SuRT & CTT). In this setting the compensative behavior from the first study emerged again. Additionally the influence of secondary task characteristics to the shown behavior (activity reduction in secondary task) and mental workload (measured by the ICA) could be proven in two different types of situations. In one situation, it was attempted to produce an uncertainty about the upcoming situation. Thereby, the situation model of the drivers should be questioned. Following that, drivers reduced their activity in the secondary task in those situations but only if they could interrupt the task without a perceived loss of performance (operating the SuRT). Drivers did not interrupt the secondary task if they expected a loss of performance (operating the CTT). Thereby, the strong effect of secondary task characteristics becomes obvious (especially the perceived loss of performance in a task if interrupted). In the condition in which participants did not reduce their activity, mental workload was increased instead. This can be interpreted as a support for the explanation of Baumann and Krems (2007). Mental resources seem to be required in order to retrieve information from the long term memory and to integrate them into the current model or to change the model. In a situation in which the situation model is questioned, the activity is reduced to potentially compensate the higher workload (if the activity is not reduced, a higher workload becomes measurable). To enable avoiding of such an increased workload, the interruptibility of a task seems to be an important factor. Only if drivers interpret a task as easy and interruptible they are likely to interrupt this task in a driving situation. In this thesis the term "perceived loss of performance" was used to describe this effect. It is expected that there is a difference between the theoretical interruptibility of a task that can be simulated for example by a cognitive architecture such as ACT-R (Salvucci, Taatgen & Borst, 2009) or estimated by the Occlusion method (Krems, Keinath, Baumann, Gelau, Bengler 2000) and the behavior drivers show in a driving situation. It is suggested that several factors play a role in a driving situation in regards to whether or not a secondary task is interrupted. What does this mean for the development of an IVIS? If a graphical user interface of a task is visually demanding, for example, or even interesting and attractive, it can interfere with the willingness to interrupt this task. These tasks can be appealing while used in the parking lot, but they also attract the attention longer than a simple and plain GUI (graphical user interface) while driving. A so-called timeout function can be another influence in this context. Thereby, a user is automatically placed back into another system state (most frequently the main menu) if no input is given for a specific time period. This may produce a lower willingness to reduce activity in a secondary task, because if this task is interrupted the perceived loss of performance would be higher than in a task with no timeout function. A lot more influencing factors are imaginable, but for a proper simulation of an interruption setting, all of those factors would have to be known. In contrast to that, an approach was chosen to measure the effect of shown interruptions in a driving situation that calls for basic driving skills on the one hand, but on the other hand gives drivers the freedom to choose by themselves how long they want to operate a task.

Therefore, a simplified setting was conducted in the third study that enables a researcher to evaluate a prototype of an IVIS based on the findings about anticipation and behavior adaptation. Furthermore, an adapted setting of the LCT was used. Lane changes were announced but the temporal distance between each lane change was presented completely randomized. In this controlled, simplified driving setting, different tasks were compared (these differed concerning their interruptibility: SuRT, CTT and two versions of an in-house developed visual search task). The results showed the expected differences in the measured data concerning whether or not a timeout function was present in a secondary task: Participants interrupted a task with a timeout function to a lesser degree than a task without one. From a methodological point of view, it is interesting that this difference could not be shown in the Occlusion method. The chosen approach is expected to deliver relevant data to evaluate IVIS in a basic, controllable driving setting.

# 3 Further implications of the presented results

In this thesis driver behavior was analyzed in different experimental settings. Thereby, it could be shown that drivers often appropriately adapt their activity in secondary tasks to the specific situation. Nevertheless, activity in the secondary task was not always reduced in an adequate way. By analyzing accidents in the real world, it has been shown that two primary types of errors cause most of the accidents in automotive traffic situations: lack of information and wrong decision/goal setting (Vollrath, Briest & Drewes, 2006). The operation of a secondary task in a driving situation can be seen as a prioritization of this task (following that line of thought, the secondary task could actually be called the primary tasks, but to stay nonambiguous it is still called secondary task here). If a driver prioritizes a secondary task in a situation that does not allow the operation of a task without a heightened risk of missing important information, such prioritization can be understood as a wrong goal setting. Thereby, the goals were not adapted to the specific situation. The consequence of such a (wrong) goal setting can also lead to the second type of error: drivers do not have the relevant information to drive accident-free.

The reasons for such improper prioritizations are not fully understood yet. One influencing factor is probably the self-assessment of drivers on their driving and dual task skills. In Fullers model of accidents (Fuller, 2005) drivers are seen in the area of conflict between the demands of the situation and their own skills. According to this model, there is a mismatch between these two factors if an accident occurs: the demands were bigger than the (compensative) skills of the driver. This also supports the thought that a higher workload is not per se lowering driving performance and leading to accidents. The fit between situation and workload is central thereby. Furthermore, the operation of a secondary task can be seen as an active driver behavior. Following that, it can be argued that the reason for an inappropriate operation of a secondary task can be an overestimation of the skills someone has, or an inappropriate assessment of the situation. The secondary task itself can play a crucial role here. One way the attributes of a secondary task influence the estimation of a situation was shown in this thesis: the perceived loss of performance that results in the interruption of a task. If drivers expect a loss of performance when they interrupt a secondary task (e.g. a task with a timeout functionality) they tend to keep on operating this task even in hazardous situations (see study 2). Such behavior can be explained by the conditioning learning theory: If someone operates a task in a hazardous situation, accidents still happen quite rarely (Reason, 1992). Following that, such behavior only rarely has direct adverse consequences or is punished. But if the driver interrupts a task with a timeout functionality, this interruption may directly lead to some kind of a punishment (the operator has to start again at the beginning of the task and the operation takes longer). Thereby, a dangerous behavior like operating a secondary task in a hazardous situation can be incited. Another way in which attributes of a secondary task influence the shown operation behavior is that depending on the way information and the interaction design are presented, a system can be highly compelling. Through this effect, drivers can be captured so much by operating a system, that they do not interrupt the secondary task in a situation in which they would normally do so. In this case it is not the driver’s goal that leads to an inappropriate behavior, but rather the interaction with the system itself. The prioritization of a driving task or a secondary task is often based on the anticipation of the development of three factors: the further development of the driving situation, the development of the workload and the secondary task (thereby especially the anticipated characteristics of the task play a crucial role, e. g. the expected interruptibility). Following these thoughts, the importance of the requested interruptibility (Leiser, 1993) of secondary tasks becomes obvious as well as the complexity of the factors influencing the interruptions of a secondary task.

The determined results in this thesis concerning the anticipation of the further development of a situation are in alignment with the approach of Baumann and Krems (Baumann & Krems, 2007; Krems & Baumann, 2009). According to their thoughts, perceived information activates knowledge structures within the long-term memory in the first phase. Afterwards, the relevant structures are integrated into the current situation model, which is defined as the generalized knowledge of a specific situation configuration. Thereby the most adequate actions for this situation are activated. The important role of anticipation could be shown in all the presented studies in one way or another. In the second study, for example, participants were informed that “some hazardous situation will occur”. The formed anticipation did not only contain a possible situation constellation, but also a direct implication for the appropriate behavior in the secondary task. Therefore the relation between the operation of a secondary task and a heightened workload was derived from long term memory; even if no specific situation was announced. The underlying thought was something like “I should reduce my activity in the secondary task because there is a demanding situation coming up and I will be overstrained, if I still operate the secondary task”. After the experience of one such situation, the effect disappeared, because participants realized that the situation was not so demanding as to result in an accident if the secondary task was still operated.

To explain the anticipative prioritization of tasks based on the expected workload, the thoughts of Hockey were combined with the concept of anticipation. Hockey (1997) postulates in his cognitive-energetical framework that in situations with high demands the effort is not automatically heightened, but a supervisory controller regulates the response due to the subjective relevance of the task. Combining this thought with the concept of anticipation, such a supervisory controller does not only regulate the actual effort but also anticipates the further needed effort to fulfill a task and adjusts the effort to do so by the subjective relevance. Following that, the actual workload does not only depend on the situation and the skills of the person, but also on the subjective rating of the task relevance and the anticipation of these factors. The rating of the task relevance is influenced by specific inter-individual preferences and traits of a person. For persons who always want to direct their complete attention on the road for example, the rating of the relevance of a secondary task is expected to be low. The importance of the specific goal that is attempted to be fulfilled by executing a task also plays a role here. If someone is late for an important meeting and wants to call the contact person, the relevance of placing a phone call may be very high and even if the workload is expected to be high while dialing, this task would most probably be executed while driving.

Concerning basic workload theories, the high adaptability of drivers could be proven in this thesis. An approach that all additional tasks increase mental workload (Pashler & Johnston, 1998) and decrease driving performance because of the limitation of resources (Kahneman, 1973), should therefore be adapted to the multifaceted influencing factors in a driving situation. In a dynamic, complex situation like a driving situation, the capabilities of drivers to influence such a situation and their own workload should not be underestimated. Drivers do not just passively react to the demands of driving situations, but actively influence and regulate them themselves. Such a goal shifting and rule activation of course also strains the control executive (Rubinstein et al., 2001) and can therefore lead to an enhanced workload. Following that, the effort that drivers show in a situation depends on the driver's condition and its environment as well as on the anticipated development of the situation and the estimated workload needed for a task.

# 4 Advantages and disadvantages of the chosen measurement approach

In all three studies the different data sets (driving behavior, operating behavior and mental workload) were evaluated in relation to each other and compared within a defined period of time (depending on the information available to the drivers). This approach has several advantages: First it is possible to measure compensative behavior between different tasks. If two IVIS are to be compared, for example, drivers could compensate the design shortcomings of one system by slowing down in the driving task. At the same time drivers could show the same total task times for completing the task. The differences between the systems are lost if driving performance is not measured. The opposite issue could also arise, in that driving performance is held stable, but total task time is higher. A third possibility is that participants increase their effort in operating the secondary task and the driving task. Thereby they could have heightened their workload but the task performance would not suffer. Following that, an analysis that takes driving task, secondary task and (if feasible) mental workload into account, facilitates a more accurate judgment of IVIS. Additionally to evaluating the data in coherence to the different factors, it seems to be crucial to synchronize the different data sets related to the actual driving situation. Driving and operating behavior can only be interpreted in an adequate way if the driving situation is well known. Activity in a secondary task can have a totally different impact on driving safety in two different situations, even if these situations are not occurring at widely disparate points in time. But if two systems are compared in the same situation and one system is still operated after the announcement of an upcoming hazardous driving situation, whereas activity is decreased in the use of another, a judgment about the respective system interruptibility can be delivered. Triggers that are automatically placed into the data stream seem to be a good way to separate the recorded data into different parts (e.g. time period between perceiving a warning signal and the first possibility to see a hazardous situation). In order to define such relevant time periods, the events in the driving task should be identified (e.g. warning signal) and rated concerning their meaning for the driving situation. This can be challenging for some situations and even if the reasonable time periods are defined, data processing can be time consuming when getting the data per participants and situation. Nevertheless, only a reasonable evaluation of relevant time periods can avoid data which contains several changes being summed up over a time period, and thus the loss of those differences due to averaging.

The described methodological challenges also occurred in the third study. Nevertheless the setting is easy to explain and usable in a simple desktop setting and it is based on the finding in the previous studies with a complex driving scenario. The idea can be summed up as follows: Drivers were informed about an upcoming driving situation that needed their attention in different time intervals. The time from signal to upcoming situation was also varied. Thereby drivers could anticipate that they should reduce their activity in the next few seconds. The time until these changes in activity occur can be measured. In this study, the activity in the secondary task was used as a measurement. This is of course only possible if input is needed to operate a task. In a conversation this proves to be more difficult to measure, but still inputs to the conversation can be measured. A central challenge for an approach like this lies in the used measurement index. A significant reduction of the input activity in the periods before and after the noise signal was interpreted as an indication of good interruptibility in this study. Methodological problems could occur while testing IVIS which require only a few regular or sporadic inputs. That is why a very low base rate of the input signals of a specific IVIS could inhibit detecting significant differences. Another possibility would be to use a percentage of the inputs before and after the signal to get a comparable value between different tasks. Several additional suggestions for future research are presented in the next chapter.

# 5 Suggestions for future research

In study two an approach is described that shows the different factors influencing the perception of a driving situation in general. Three factors were identified that should be taken into account if a dual task situation while driving is analyzed. Several optional interactions were discussed, but the focus lay on the influence of the attributes of the secondary task. Nevertheless several other interactions between the factors are possible and should be further analyzed, e.g.: What attributes of a driving task influence the activity in a secondary task, beside the anticipation of a critical driving event? How do differences concerning skills or different goal settings of the driver influence the relationship between workload and driving task? These questions should be answered and integrated into the approach to get a more holistic picture of how drivers manage different tasks at the same time.

As described in the previous chapter, the chosen approach in the third study (to evaluate an IVIS concerning its use while driving) is not evaluated in a comprehensive way yet. Several challenges have to be solved before this method can be used regularly to evaluate IVIS. At first, the measurement index has to be tested and compared in different settings and different tasks. Therefore several parameters of the setting should be varied (e.g. the time period from signal to critical situation or the distance and number of the lane changes). The time period between signal and lane change should not be too long (thus drivers would not use the signal as a valid announcement of the situation) but the time period should also not be too short (thus the time period would be that short that hardly any differences between different systems could be found). Additionally, different tasks should be used to cross-check the measured data with the expected data (e.g. tasks that need no haptic input or visual control). Also the instruction of the secondary tasks should be varied. Thereby it would be also possible to analyze how easily the prioritization of tasks can be influenced by the instruction. In the presented studies the focus lied on the perceived interruptibility of a secondary task and how this influences behavior adaptations. Nevertheless other influencing factors are possible and should be further analyzed (e.g. instructions, pressure to perform, skills and also other properties of IVIS that make a system highly compelling).

Inter individual differences were not evaluated exhaustively in this thesis; general driving behavior and the influences of IVIS while driving were analyzed, not specific subgroups of drivers. Nevertheless, it would be interesting to identify such subgroups and test if their behavior differs between each other. One option could be to group participants according to their driving styles (for example by a driving style questionnaire) and to test if drivers with a more risky driving style tend to operate secondary tasks longer or more intensively than drivers that are more safety oriented for example.

Another possible segmentation would be to separate drivers according to their driving experience and age (e.g. as Bühler, Rösler, Wege & Krems, 2009; Hosking, Young & Regan, 2009). Thereby, interesting questions could be evaluated: Do drivers interrupt a secondary task earlier or later if behavior becomes more automated in complex driving situation by experience? A reduction of needed workload by automating processes could lead to a longer usage of systems after a warning signal. Another interesting question concerning the experience of drivers is how situation models change in relation to driving experience. It can be expected that the longer someone drives a car the more situations he or she has experienced and the more complex the situation model becomes. It is expected that more features and also distinctive features are contained in such a model, as well as more possible actions to handle a situation being assigned to it. The adequate adaptation of activity in a secondary task could therefore be chosen specifically to a situation, because a more precise anticipation of the future development of a situation can be done. On the other hand such a trust in one’s own anticipation can also lead to an inappropriate certainty about the future development of a situation. Thus, stimuli can be overlooked because they do not fit into the actual situation model. This leads to another question: What are the reasons for a breakdown of the normally appropriate behavior adaptations, so that dangerous situations do occur? One important influence factor certainly is an IVIS that is not designed appropriately to drivers. Nevertheless, to develop and evaluate an IVIS in a proper way it should be taken into account and if possible, supported, that drivers are able to anticipate driving situations, adapt their behavior accordingly and manage even complex situations successfully.

## References


Alliance of Automobile Manufacturers Driver Focus-Telematics Working Group (2003). *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems.*

Alm, H., & Nilsson, L. (1995). The Effects of a Mobile Telephone Task on Driver Behaviour in a Car Following Situation, *Accident Analysis and Prevention*, 27, 707-715.

Antin, J. (1993). Informational Aspects of Car Design: Navigation. In B. Peacock & W. Karwowski (Eds.), *Automotive Ergonomics* (pp. 321-337). London, Washington, DC: Taylor and Francis.

Baumann, M., & Krems, J. F. (2007). Situation awareness and driving: A cognitive model. In P. C. Cacciabue (Ed.), *Modelling driver behaviour in automotive environments. Critical issues in driver interactions with intelligent transport systems* (pp. 253-265). London: Springer.

Baumann, M., Petzoldt, T., Groenewoud, C., Hogema, J., & Krems, J. F. (2008). The effect of cognitive tasks on predicting events in traffic. In C. Brusque (Ed.), *Proceedings of the European Conference on Human Interface Design for Intelligent Transport Systems* (pp. 3-11). Lyon: Humanist Publications.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*, 4(10), 829–839.

Beede, K. E., & Kass, S. J. (2006). Engrossed in conversation: The impact of cell phones on simulated driving performance. *Accident Analysis and Prevention*, 38, 415-421.

Bortz, J., & Döring, N. (2002). *Forschungsmethoden und Evaluation*, 3. Auflage. Berlin, Germany: Springer.

Brookhuis, K. A., de Vries, G., & de Waard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention, 23*, 309-316.

Bühler, F., Rösler, D., Wege, C., & Krems, J. F. (2009). Driving experience matters! Comparison of experienced and inexperienced drivers in driving situations of varying complexity. In A. Lichtenstein, C. Stößel, & C. Clemens (Eds.), *Der Mensch im Mittelpunkt technischer Systeme. 8. Berliner Werkstatt Mensch-Maschine-Systeme* (pp. 104-109). Düsseldorf, Germany: VDI Verlag.

Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C. (2008). A meta-analysis of the effects of cell phones on driver performance. *Accident Analysis and Prevention, 40,* 1282–1293.

Carsten, O., Merat, N., Janssen, W. H., Johansson, E., Fowkes, M., & Brookhuis, K. A. (2005). *HASTE Final Report*. European Commission.

Cnossen, F., Meijman, T., & Rothengatter, T. (2004). Adaptive strategy changes as function of task demands: a study of car drivers. *Ergonomics*, 47(2), 217-236.

Daubechies, I. (1988). Orthonormal bases of compactly supported wavelets. Communications in Pure and Applied Mathematics, 41, 909-996.

de Waard, D. (1996). *The measurement of drivers' mental workload*. (Doctoral dissertation). Haren, The Netherlands: The Traffic Research Centre VSC, University of Groningen.

Dingus, T. A., Klauer, S. G., Neale, V. L., G.T., Petersen, A. Lee, S. E., Sudweeks, J., Perez, M.A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J., & Knipling, R. R. (2006): *The 100 car naturalistic driving study. Phase II-Results of the 100 car field study*, Report Nummer DOT HS 810 593. Washington: NHTSA.

Drews, F., Yazdani, H., Godfrey, C., Cooper, J., & Strayer, D. (2009). Text messaging during simulated driving. *Human Factors*, 51, 762-770.

Endsley, M. R. (1995a). Measurement of situation awareness in dynamic systems. *Human Factors*, 37 (1), 65-84.

Endsley, M.R. (1995b). Toward a theory of situation awareness in dynamic systems. *Human Factors* 37, (2), 381-394.

Engström, J., Johansson, E., & Östlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part* F, 8, 97-120.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, 102, 211-245.

Commission of the European Communities (2008). Commission recommendation of 26 May 2008 on safe and efficient in-vehicle information and communication systems: Update of the European statement of principles on human-machine interface. *Official Journal of the European Communities, L216*, 1-42.

Farmer, E. & Brownson, A. (2003). Review of workload measurement, analysis and interpretation methods. European Organization for the Safety of Air Navigation: 33. Retrieved from:

http://www.eurocontrol.int/integra/gallery/content/public/documents/expt_def_wp2_final.pdf

Fuller, R. (2005). Towards a general theory of driver behavior. *Accident Analysis & Prevention*, 3, 461-472.

Gelau, C., & Krems, J. F. (Eds.). (2004). The occlusion technique: A procedure to assess the HMI of in-vehicle information and communication systems. *Applied Ergonomics,* 35 (3), 185-187.

Gelau, C., Henning, M., & Krems, J. F. (2009). On the reliability of the occlusion technique as a tool for the assessment of the HMI of in-vehicle information and communication systems. *Applied Ergonomics, 40,* 181-184.

Greenberg, J., Tijerina, L., Curry, R., Artz, B., Cathey, L., Grant, P., Kochhar, O., Kozak, K., & Blornmer, M. (2003). Evaluation of Driver Distraction Using an Event Detection Paradigm. *Transportation Research Board 82nd Annual Meeting Compendium of Papers*. Transportation Research Board, Washington, DC.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: P. A. Hancock and N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). North-Holland: Elsevier Science.

Hess, E. H., & Polt, J. M. (1964). Pupil size in relation to mental activity during simple problem-solving. *Science*, 143(3611), 1190-1192.

Hilburn, B., & Jorna, P. G. (2001). Workload and air traffic control. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload and fatigue*. Mahwah: L. Erlbaum.

Hockey, G. R. J. (1997). Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. *Biological Psychology*, 45, 73-93.

Hollnagel E., & Woods, D. D. (2005). *Joint cognitive systems: Foundations of cognitive systems engeneering*. Boca Raton, Fla.: CRC.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention, 38*, 185-191.

Horrey, W. J., & Wickens, C. D. (2002). Driving and side task performance: the effects of display clutter, separation and modality (Technical Report ARL-02-13/GM- 02-2). Savoy, IL: University of Illinois, Aviation Human Factors Division.

Hosking, S., Young, K., & Regan, M. (2009). The effects of textmessaging on young drivers. *Human Factors*, 51, 582-592.

ISO 15008. (2009). Road vehicles - Ergonomic aspects of transport information and control systems - Specifications and test procedures for in-vehicle visual presentation. Geneva, Switzerland: ISO.

ISO 16673. (2007). Road vehicles - Ergonomic aspects of transport information and control systems - Occlusion method to assess visual demand due to the use of in-vehicle systems. Geneva, Switzerland: ISO.

Ishida, T., & Matsuura, T. (2001). The effect of cellular phone use on driving performance. *International Association of Traffic Safety Sciences Research*, 2S, 6-14.

Jamson, A. H., & Merat, N. (2005). Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. *Transportation Research Part F, 8* (2), 79-96.

Jordan, P. W., & Johnson, G. I. (1993). Exploring mental workload via TLX: The case of operating a car stereo whilst driving. In: A.G. Gale, I.D. Brown, C.M. Haslegrave, H. W. Kruysse & S. P. Taylor (Eds.), *Vision in Vehicles-IV* (pp. 255-262). Amsterdam: North-Holland.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs: Prentice Hall.

Kantowitz, B. H., & Sorkin, R. D. (1983). *Human Factors: Understanding people-system relationships*. New York: John Wiley & Sons.

Keinath, A., Baumann, M., Gelau, C., Bengler, K., & Krems, J. F., (2001). Occlusion as a technique for evaluating in-car displays. In D. Harris (Ed.), Eng*ineering Psychology and Cognitive Ergonomics*, Vol. 5. (pp. 391–397). Ashgate Publishing Ltd., Aldershot, UK.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. New York: Cambridge University Press.

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J.D., & Ramsey, D. J. (2006). *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data* (Report: DOT HS 810 594). Washington, DC: NHTSA.

Knappe, G. (2009). Empirische Untersuchungen zur Querregelung in Fahrsimulatoren (Doctoral dissertation). Retrieved from http://www.opus.ub.uni-erlangen.de/opus/volltexte/2010/1576/pdf/GwendolinKnappeDissertation.pdf

Krems, J. F., Keinath, A., Baumann, M., Gelau, C., & Bengler, K. (2000). Evaluating visual display designs in vehicles: Advantages and disadvantages of the occlusion technique. In L. M. Camarinha-Matos, H. Afsarmanesh & H.-H. Erbe (Eds.), *Advances in Network Enterprises* (pp. 361-368). Boston: Kluwer.

Krems, J. F., & Baumann, M. (2009). Driving and Situation Awareness: A Cognitive Model of Memory-Update Processes. In M. W. Greenlee (Ed.), *New Issues in Experimental and Applied Psychology* (S. 56-75). Lengerich: Pabst.

Kushleyeva, Y., Salvucci, D. D., & Lee, F. J. (2005). Deciding when to switch tasks in time-critical multitasking. *Cognitive Systems Research*, 6, 41-49.

Leiser, R. (1993). Driver-vehicle interface: Dialogue design for voice input. In A. M. Parkes & S. Franzen (Eds.), *Driving Future Vehicles* (pp. 275-293). Washington, D.C.: Taylor & Francis.

Lerner, N., & Boyd, S. (2005). *On-Road Study of Willingness to Engage in Distracting Tasks* (No. DOT HS-809-863). Washington, DC: National Highway Traffic Safety Administration.

Manalavan, P., Samar, A., Schneider, M., Kiesler, S., & Siewiorek, D. (2002). In-car cell phone use: mitigating risk by signaling remote callers. CHI Extended abstracts on Human Factors in Computing Systems, (pp. 790-791). ACM Press.

Mattes, S. (2003). The lane-change-task as a tool for driver distraction evaluation. In H. Strasser et al. (Eds.), *Quality of work and products in enterprises of the future* (pp. 57-60). Stuttgart: Ergonomia.

Mattes, S., & Hallén, A. (2009). Surrogate distraction measurement techniques: the lane change task. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver distraction* (pp. 107-122). New York: CRC.

Marshall, S. P. (2005). *Assessing cognitive engagement and cognitive state from eye metrics. Las Vegas, NV: Proceedings of the 1st International Conference on Augmented Cognition.*

Marshall, S. P. (2007). Identifying cognitive state from eye metrics. *Aviation, Space, And Environmental Medicine*, 78 (5), 165-175.

McFarlane, D.C. (2002). Comparison of four primary methods for coordinating the interruption of people in human–computer interaction. *Human-Computer interaction*, 17(1), 63-139.

McFarlane, D. C., & Latorella, K.A. (2002). The scope and importance of human interruption in human-computer interaction design. *Human-Computer interaction*, 17(1), 1-61.

Michon, J.A. (1985). A critical review of driver behavior models: What do we know, what should we do? In L. A. Evans & R. C. Sching (Eds.), *Human behavior and traffic safety* (pp. 487-525). New York: Plenum Press.

Milicic, N. (2010). *Sichere und ergonomische Nutzung von Head-Up Displays im Fahrzeug. (Doctoral Dissertation)*. Retrieved from http://nbn-resolving.de/urn/resolver.pl?urn:nbn:de:bvb:91-diss-20100420-817137-1-7

NHTSA Publication 811171 (2008). *Traffic Safety Facts Data Summary Booklet*. Washington, DC: NHTSA. Retrieved from http://www-fars.nhtsa.dot.gov

NHTSA Publication 0053 (2012). *Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices.* Washington, DC: NHTSA. Retrieved from

http://www.nhtsa.gov/search?q=Docket+No.+NHTSA-2010-0053&x=0&y=0

Niedermaier, B., Durach, S., Eckstein, L., & Keinath, A. (2009). The new BMW iDrive – Applied processes and methods to assure high usability. *Lecture notes in computer science*, 5620/2009, 443-452.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. Reprinted in revised form. In R. J. Davidson, G.E. Schwartz, D. Shapiro (Eds.), *Consciousness and self-regulation* Vol. 4 (pp. 1–18). New York, NY: Plenum Press.

Noy, Y. I., Lemoine, T. L., Klachan, C., & Burns, P. C. (2004). Task interruptability and duration as measures of visual distraction. *Applied Ergonomics*, 35 (3), 207-213.

Östlund, J., Peters, B., Thorslund, B., Engström, J., Markkula, G., Keinath, A., & Foehl, U. (2005). Driving performance assessment: Methods and metrics. AIDE Deliverable 2.2.5. IST-1-507674-IP, European Commission. Retrieved from

http://www.aide-eu.org/pdf/sp2_deliv_new/aide_d2_2_5.pdf

O'Donnell, R. D., & Eggemeier, F. T. (1986). Workload assessment methodology. In K. R. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of perception and human performance. Volume II, Cognitive processes and performance* (pp. 42/1-42/49). New York, NY: Wiley.

Owens, J. M., McLaughlin, S. B., & Sudweeks, J. (2011). Driver performance while text messaging using handheld and in-vehicle systems. *Accident Analysis and Prevention, 43*, 939-947.

Pohlmann, S., & Tränkle, U. (1994). Orientation in road traffic. Age-related differences using an in-vehicle navigation system and a conventional map. *Accident Analysis and Prevention*, 26(6), 689-702.

Pashler, H., & Johnston, J. C. (1998). Attentional limitations in dual-task performance. In H. Pashler (Ed.), *Attention* (pp. 155-185). East Sussex, UK: Psychology Press.

Pauzié, A., & Manzano, J. (2007). *Evaluation of driver mental workload facing new in-vehicle information and communication technology*. INRETS - National Research Institute on Transport and Safety.

Rauch, N. (2009). *Ein Verhaltensbasiertes Messmodell zur Erfassung von Situationsbewusstsein im Fahrkontext* (Doctoral dissertation). Retrieved from

http://www.psychologie.uni-wuerzburg.de/methoden/texte/2009_Rauch_Diss.pdf

Rauch, N., Gradenegger, B., & Krüger, H.-P. (2009). Darf ich oder darf ich nicht? Situationsbewusstsein im Umgang mit Nebenaufgaben während der Fahrt. *Zeitschrift für Arbeitswissenschaften*, 1(9), 3-17.

Reason, J. (1992). *Human Error*. Cambridge: University Press.

Regan, M. A., Lee, J. D., Young, K. L., & Gordon, C. P. (2009). In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects, and mitigation* (pp. 249-280). Boca Raton, Fla.: CRC Press.

Rockwell, T. H. (1988). Spare visual capacity in driving-revisited: new empirical results for an old idea. In A. G. Gale, M. H. Freeman, C. M. Haslegrav, P. Smith, & S. P. Taylor (Eds.), *Vision in vehicles – II* (pp. 317–324). Amsterdam: North-Holland.

Rogers, R. D., & Monsell, S. (1995). Cost of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: Human Perception and Performance*, 124, 207-231.

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive Control of Cognitive Processes in Task Switching. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 763-797.

Sacher, H. (2009). *Gesamtheitliche Analyse des Bedienverhaltens von Fahrzeugfunktionen in der täglichen Nutzung.* (Doctoral Dissertation). Retrieved from

http://d-nb.info/994227191/34

Salvucci, D. D. (2005). A multitasking general executive for compound continuous tasks. *Cognitive Science*, 29, 457-492.

Salvucci, D. D., Taatgen, N. A., & Borst, J.P. (2009). Toward a Unified Theory of the Multitasking Continuum: From Concurrent Performance to Task Switching, Interruption, and Resumption. In *Human Factors in Computing Systems: CHI 2009 Conference Proceedings* (pp. 1819-1828). New York: ACM Press. Retrieved from https://www.cs.drexel.edu/~salvucci/publications/Salvucci-CHI09.pdf

Sayer, J. R., Devonshire, J., & Flannagan, C. A. (2005). Effects of secondary tasks on driving performance (*Report No. UMTRI-2005-29*). Ann Arbor: The University of Michigan Transportation Research Institute.

Schießl, C., Vollrath, M., Dambier, M., Altmüller, T., & Kornblum, C. (2005). Was ist eigentlich beanspruchend? Das Fahren selbst oder die Situation? In L. Urbas & C. Steffens (Eds.), *Zustandserkennung und Systemgestaltung. 6. Berliner Werkstatt Mensch-Maschine-Systeme,* Vol. 19 (pp. 95 - 100). Berlin, Germany: VDI Verlag GmbH.

Schwalm, M., Keinath, A., & Zimmer, H., (2008). Pupillometry as a method for measuring mental workload within a simulated driving task. In D. de Waard, F.O. Flemisch, B.

Lorenz, H. Oberheid, & K.A. Brookhuis (Eds.), *Human Factors for assistance and automation* (pp. 75 - 88). Maastricht, the Netherlands: Shaker Publishing.

Schwalm, M. (2009). *Pupillometrie als Methode zur Erfassung mentaler Beanspruchungen im automotiven Kontext*. (Doctoral dissertation). Retrieved from http://scidok.sulb.uni-saarland.de/volltexte/2009/2082/pdf/Dissertation_Maximilian_Schwalm.pdf

Srinivasan, R., & Jovanis, P. P. (1997). Effect of in-vehicle route guidance systems on driver workload and choice of vehicle speed: Findings from a driving simulator experiment. In Y. I. Noy (Ed.), *Ergonomics and safety of intelligent driver interfaces* (pp. 97-114). Mahwah, New Jersey: Lawrence Earlbaum Associates.

Staal, M. (2004). *Stress, Cognition, and human Performance: A Literature Review and Conceptual Framework*: NASA. Retrieved from

http://human-factors.arc.nasa.gov/flightcognition/Publications/IH_054_Staal.pdf

Stutts, J. C., & Hunter, W. W. (2003). Driver inattention, driver distraction and traffic crashes. I*TE Journal*, 73(7), 34-45.

Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science*, 12, 462–466.

Tanida, K., & Pöppel, E. (2006). A hierarchical model of operational anticipation windows in driving an automobile. *Cognitive Processing*, 7, 275-287.

Tijerina, L., Parmer, E., & Goodman, M. J. (1998). Driver workload assessment of route guidance system destination entry while driving: A test track study. In *Proceedings of the 5th ITS World Congress*, Seoul, Korea.

Tijerina, L. (2001). *Issues in the evaluation of driver distraction associated with in-vehicle information and telecommunications systems*. East Liberty, OH: Transportation Research Center.

Törnros, J., & Bolling, A. (2006). Mobile phone use – effects of conversation on mental workload and driving speed in rural and urban environments. *Transportation Research Part F, 9,* 298–306.

Young, K., Regan, M., & Hammer, M. (2003). *Monash University Accident Research Centre - Report #206 – 2003*. Retrieved from

http://www.monash.edu.au/miri/research/reports/muarc206.html

Vollrath, M., Briest, S., & Drewes, J. (2006). Ableitung von Anforderungen an ein Fahrerassistenzsystem aus Sicht der Verkehrssicherheit. *Berichte der Bundesanstalt für Straßenwesen, Fahrzeugtechnik*, Heft F 60. Bremerhaven: Wirtschaftsverlag NW.

Vollrath, M., & Krems, J. F. (2011). Verkehrspsychologie. *Ein Lehrbuch für Psychologen, Ingenieure und Informatiker*. Stuttgart: Kohlhammer.

Wharton, C., Rieman, J., Lewis, C., & Polson P. (1994). The cognitive walkthrough method. A practioner's guide. In J. Nielsen & R. L. Mack (Eds.), *Usability Inspection Methods (pp.* 105–140). New York, NY: John Wiley & Sons.

Wickens, C. D. (1984). Processing Ressources in attention. In Parasuraman & D. R. Davis (Eds.), *Varieties of attention* (pp. 63-102). London, UK: Academic Press.

Wickens, C. D., & Hollands, G. (2000). *Engineering Psychology and Human Performance* (3rd ed.). New Jersey: Prentice Hall.

Wickens, C. D., Goh, J., Helleberg, J., Horrey, W., & Talleur, D. A. (2003). Attentional models of multi-task pilot performance using advanced display technology. *Human Factors*, 45, 360-380.

Williams, L. J. (1985). Tunnel vision induced by a foveal load manipulation. *Human Factors*, 27, 221-227.

# Eidesstattliche Erklärung

Hiermit erkläre ich, Frederik Platten, geboren am 10. März 1981 in Köln, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Hilfsmittel verwendet habe.

Frederik Platten

Köln, den

## Curriculum Vitae

Frederik Platten

Industriestraße 20-30

51399 Burscheid, Germany

Mobile: +49 162 109 1375

e-mail: Frederik.Platten@jci.com

Date of birth: 10. March 1981

Place of birth: Cologne

Nationality: German

| | |
|---|---|
| 04/2011-until now | **Johnson Controls GmbH**, Burscheid<br>Specialist New Technologies |
| 04/2008 – 03/2011 | **BMW Group,** Forschungs- und Innovationszentrum, Munich<br>PhD student |
| 06/2007 – 02/2008 | **BMW Group**, Forschungs- und Innovationszentrum, Munich<br>Diploma thesis: „Analyse von Bearbeitungsstrategien in Fahrsituationen mit Hilfe der Pupillometrie zur verbesserten Bewertung von Anzeige- und Bedienkonzepten.“ |
| 10/2001 – 03/2008 | **Universität Trier,** Trier<br>Psychology Diploma, Grade: 1.3 |